

METHODS OF INHIBITING TUMOR CELL PROLIFERATION

BACKGROUND OF THE INVENTION

This application is related to and claims priority to U.S. provisional application
5 Serial No. 60/457,257 filed March 25, 2003, U.S. provisional application Serial No.
60/474,075 filed May 29, 2003, U.S. provisional application Serial No. 60/513,809 filed
October 23, 2003, U.S. provisional application Serial No. 60/540,691 filed January 30,
2004, and U.S. provisional application Serial No. 60/549,211 filed March 2, 2004, the
disclosure of each of which is incorporated by reference herein.

10 These studies were funded by grants from the National Institute on Aging, grant
number AG21842-02, and the National Institute of Diabetes and Digestive and Kidney
Diseases, grant number DK54687-06. The U.S. government may have certain rights to
this invention.

1. Field of the Invention

The invention relates to methods of inhibiting tumor cell proliferation by
inhibiting FoxM1B activity. Specifically, the invention relates to methods of inhibiting
tumor cell proliferation by inhibiting FoxM1B activity, expression, or nuclear
localization in a tumor cell. The invention also relates to screening methods for
20 identifying compounds that can inhibit tumor cell growth by inhibiting FoxM1B activity,
expression, or nuclear localization in a tumor cell.

2. Background of the Related Art

The Forkhead box transcription factors have been implicated in regulating cellular longevity and proliferative capacity. Such studies include a finding of increased longevity in *C. elegans* bearing a mutant *daf-2* gene, which encodes the worm homolog of the insulin/Insulin-like Growth Factor 1 (IGF1) receptor (Lin *et al.*, 1997, *Science* 278: 1319-1322; Ogg *et al.*, 1997, *Nature* 389: 994-999). Disruption of the *daf-2* gene abolishes insulin-mediated activation of the phosphatidylinositol 3-kinase (PI3K) - protein kinase B/Akt (Akt) signal transduction pathway and prevents inhibition of the forkhead transcription factor *daf-16* (corresponding to mammalian homologs FoxO1 or Fkhr) (Paradis and Ruvkun, 1998, *Genes Dev.* 12: 2488-2498). Activation of the PI3K/Akt pathway phosphorylates the C-terminus of the *Daf-16* (FoxO1; Fkhr) gene product and mediates its nuclear export into the cytoplasm, thus preventing FoxO1 transcriptional activation of target genes (Biggs *et al.*, 1999, *Proc. Natl. Acad. Sci. USA* 96: 7421-7426; Brunet *et al.*, 1999, *Cell* 96: 857-68; Guo *et al.*, 1999, *J. Biol. Chem.* 274: 17184-17192).

More recent studies of *Daf-2* *C. elegans* mutants have demonstrated that *Daf-16* stimulates expression of genes that limit oxidative stress (Barsyte *et al.*, 2001, *FASEB J.* 15: 627-634; Honda *et al.*, 1999, *FASEB J.* 13: 1385-1393; Wolkow *et al.*, 2000, *Science* 290: 147-150) and that the mammalian *FoxO1* gene could functionally replace the *Daf-16* gene in *C. elegans* (Lee *et al.*, 2001, *Curr. Biol.* 11: 1950-1957). In proliferating mammalian cells, the PI3K/Akt signal transduction pathway is essential for G1 to S-phase progression because it prevents transcriptional activity of the FoxO1 and FoxO3 proteins, which stimulate expression of the CDK inhibitor p27^{kip1} gene (Medema *et al.*, 2000, *Nature* 404: 782-787). Moreover, genetic studies in budding yeast demonstrated

that forkhead Fkh1 and Fkh2 proteins are components of a transcription factor complex that regulates expression of genes critical for progression into mitosis (Hollenhorst *et al.*, 2001, *Genes Dev.* 15: 2445-2456; Koranda *et al.*, 2000, *Nature* 406: 94-98; Kumar *et al.*, 2000, *Curr. Biol.* 10: 896-906; Pic *et al.*, 2000, *EMBO J.* 19: 3750-3761).

5 Forkhead Box M1B (FoxM1B) transcription factor (also known as *Trident* and *HFH-11B*) is a proliferation-specific transcription factor that shares 39% amino acid homology with the HNF-3 winged helix DNA binding domain. The molecule also contains a potent C-terminal transcriptional activation domain that possesses several phosphorylation sites for M-phase specific kinases as well as PEST sequences that
10 mediate rapid protein degradation (Korver *et al.*, 1997, *Nucleic Acids Res.* 25: 1715-1719; Korver *et al.*, 1997, *Genomics* 46: 435-442; Yao *et al.*, 1997, *J. Biol. Chem.* 272: 19827-19836; Ye *et al.*, 1997, *Mol. Cell Biol.* 17: 1626-1641).

In situ hybridization studies have shown that FoxM1B is expressed in embryonic liver, intestine, lung, and renal pelvis (Ye *et al.*, 1997, *Mol. Cell Biol.* 17: 1626-1641). In
15 adult tissue, however, FoxM1B is not expressed in postmitotic, differentiated cells of the liver and lung, although it is expressed in proliferating cells of the thymus, testis, small intestine, and colon (*Id*). FoxM1B expression is reactivated in the liver prior to hepatocyte DNA replication following regeneration induced by partial hepatectomy (*Id*).

FoxM1B is expressed in several tumor-derived epithelial cell lines and its
20 expression is induced by serum prior to the G₁/S transition (Korver *et al.*, 1997, *Nucleic Acids Res.* 25: 1715-1719; Korver *et al.*, 1997, *Genomics* 46: 435-442; Yao *et al.*, 1997, *J. Biol. Chem.* 272: 19827-19836; Ye *et al.*, 1997, *Mol. Cell Biol.* 17: 1626-1641). Consistent with the role of FoxM1B in cell cycle progression, elevated FoxM1B levels

are found in numerous actively-proliferating tumor cell lines (Korver *et al.*, 1997, *Nucleic Acids Res.* 25: 1715-1719; Yao *et al.*, 1997, *J. Biol. Chem.* 272: 19827-36; Ye *et al.*, 1997, *Mol. Cell Biol.* 17: 1626-1641). Increased nuclear staining of FoxM1B was also found in human basal cell carcinomas (Teh *et al.*, 2002, *Cancer Res.* 62: 4773-80),
5 suggesting that FoxM1B is required for cellular proliferation in human cancers.

These studies and others suggest that FoxM1B plays some role in human cancers. FoxM1B, therefore, would provide an attractive target for anti-cancer therapies because FoxM1B expression typically declines during normal aging (see co-owned and co-pending U.S. provisional patent application, Serial number 60/426,068, filed November
10 13, 2002, incorporated by reference herein). Thus, FoxM1B might provide a selective target that is more active in tumor cells than in normal cells, particularly terminally-differentiated, aged or aging normal cells that surround a tumor, allowing tumor cells to be treated while minimizing the deleterious side-effects of such compounds on normal cells.

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SUMMARY OF THE INVENTION

The invention provides methods of inhibiting proliferation of a tumor cell, comprising the step of inhibiting FoxM1B activity in the tumor cell. The methods of the invention can be accomplished by regulating FoxM1B activity through any of the
20 mechanisms as described herein, including but not limited to inhibiting FoxM1B-dependent transcription activity by interfering with binding of either Cdk2-Cyclin E/A or Cdk1-Cyclin B complexes, preventing or reducing phosphorylation of Threonine 596 in

the FoxM1B protein (both of which will significantly reduce Foxm1b transcriptional activity) or inhibiting nuclear localization of FoxM1B protein.

In one aspect of the invention, cellular FoxM1B activity is inhibited by causing FoxM1B protein to localize in the tumor cell cytoplasm or to localize to the nucleolus of the tumor cell nucleus and/or preventing or inhibiting translocation of FoxM1B to the cell nucleus. Causing FoxM1B protein to localize in the cytoplasm can be accomplished, for example, by contacting a cell with a compound that causes FoxM1B to translocate from the nucleus to the cytoplasm, or that sequesters FoxM1B in the cytoplasm and prevents FoxM1B from translocating from the cytoplasm to the nucleus. Causing FoxM1B protein to localize in the nucleolus of the nucleus can occur when FoxM1B protein interacts with the tumor suppressor p19^{ARF} protein or a peptide containing the p19^{ARF} sequences 26-44 or compounds that mimic p19^{ARF} function. Such compounds can be identified using screening methods of the invention as described herein.

In another aspect, FoxM1B activity can be inhibited by contacting a tumor cell with an antisense oligonucleotide, wherein the antisense oligonucleotide is complementary to nucleic acid sequences of RNA or double-stranded DNA that encodes FoxM1B and which inhibits FoxM1B gene expression. Preferably, an antisense oligonucleotide of the invention comprises a nucleotide sequence that is complementary to nucleotides 1-2700 of FoxM1B cDNA.

In another aspect, FoxM1B activity can be inhibited by contacting a cell, preferably a tumor cell, with a peptide having an amino acid sequence of the p19^{ARF} tumor suppressor protein as set forth in SEQ ID NO: 10 (rrrrrrrrK FVRSRRPRTASCALAFVN; referred to herein as the (D-Arg)₉-p19^{ARF} 26-44

peptide), SEQ ID NO: 11 (KFVRSRRPRTASCALAFVN; referred to herein as the p19^{ARF} 26-44 peptide), or SEQ ID NO: 12 (KFVRSRRPRTASCALAFVNMLLRILERIL RR; referred to herein as the p19^{ARF} 26-55 peptide).

In yet another aspect, FoxM1B activity can be inhibited indirectly by interfering
5 with or inhibiting activity of endogenous proteins necessary to activate FoxM1B. For example, FoxM1B activity can be inhibited by interfering with the ability of FoxM1B to interact with p300/CBP or by inhibiting CDK1 phosphorylation of FoxM1B. In addition, a tumor cell can be contacted with a tyrphostin, for example, a Jak2 kinase inhibitor, such as AG490, to inhibit FoxM1B activity. Jak2 kinase inhibitors can inhibit FoxM1B
10 activity by interfering with the ability of growth factors, such as growth hormone, to activate FoxM1B. Other inhibitors of FoxM1B activity are provided in the Examples below, for example, alsterpaullone, Akt inhibitor, U0126, and Ly294002.

The methods of the invention can be used to inhibit growth of any tumor cell that expresses FoxM1B protein or that is derived from a cell that expressed FoxM1B protein.
15 A cell that expressed FoxM1B protein can be, for example, a cell from an aging individual, wherein expression of FoxM1B protein is diminished as a result of aging. In a particular aspect, the methods of the invention can be used to inhibit tumor cell growth *in vitro* (*i.e.* under cell culture conditions) or *in vivo* (*i.e.* in a live animal). In other aspects, the methods of the invention can be used to inhibit growth of tumor cells that are
20 derived from benign or malignant tumors. In a particular aspect, the tumor cells are of epithelial cell origin, for example, from liver, lung, skin, intestine (small intestine or colon), spleen, prostate, breast, brain, or thymus cells. The tumor cells can also be of

mesoderm cell origin, for example, from liver, lung, skin, intestine (small intestine or colon), spleen, prostate, breast, brain, bone marrow or thymus cells.

The invention also provides methods for inhibiting tumor growth in an animal comprising administering to an animal, bearing at least one tumor cell present in its body, a therapeutically effective amount of a FoxM1B inhibitor for a therapeutically effective period of time. In one aspect, the FoxM1B inhibitor can be an antisense oligonucleotide, wherein the antisense oligonucleotide is complementary to nucleic acid sequences of RNA or double-stranded DNA that encodes FoxM1B and which inhibits FoxM1B gene expression. In another aspect, the FoxM1B inhibitor can be a compound that inhibits FoxM1B activity. Such compounds can be identified using screening methods of the invention as described herein. In yet another aspect, the FoxM1B inhibitor can be a peptide having an amino acid sequence as set forth in SEQ ID NO: 10, SEQ ID NO: 11, or SEQ ID NO: 12, for a therapeutically effective period of time. In additional aspects, a combination of peptides that inhibit FoxM1B activity can be administered to the animal. For example, peptides having an amino acid sequence as set forth in SEQ ID NO: 10 can be administered with peptides having an amino acid sequence as set forth in SEQ ID NO: 11 and/or SEQ ID NO: 12. One of skill in the art will recognize that any combination of these peptides can be administered to the animal bearing at least one tumor cell in its body.

The invention also provides screening methods for identifying compounds that prevent tumor progression comprising the steps of: contacting with a candidate compound a plurality of cells comprising a FoxM1B gene, wherein the cells express FoxM1B protein when cultured *in vitro*; assaying FoxM1B localization in the cells; and

identifying a candidate compound when FoxM1B is localized in the cytoplasm and not in the nuclei of cells contacted with the compound but localized in the nuclei of cells not contacted with the compound. In one aspect, the compounds identified in this screening method of the invention can prevent tumor progression (*i.e.* inhibit tumor cell proliferation and/or de-differentiation of a tumor cell) in a patient when administered to a patient who has at least one tumor cell present in his body.

The invention further provides screening method for identifying compounds that inhibit tumor progression comprising the steps of: contacting with a candidate compound a plurality of cells comprising a FoxM1B gene, wherein the cells express FoxM1B protein when cultured *in vitro*; assaying FoxM1B localization in the cells; selecting a candidate compound when FoxM1B is localized in the cytoplasm and not in the nuclei of cells contacted with the compound but localized in the nuclei of cells not contacted with the compound; and identifying a compound as a compound that can inhibit tumor progression if proliferation of tumor cells is inhibited when contacted with the compound.

In addition, the invention provides screening methods for identifying compounds that inhibit nuclear localization of FoxM1B protein, comprising the steps of: contacting a cell with a compound, wherein the cell expresses a green fluorescent protein-FoxM1B (GFP-FoxM1B) fusion protein; contacting the cell with growth hormone; detecting localization of the GFP-FoxM1B protein in the cells; and identifying a compound as a compound that inhibits FoxM1B localization if the GFP FoxM1B protein is localized in the cytoplasm and not the nuclei of the cells.

The invention also provides screening method for identifying compounds that inhibit nuclear localization of FoxM1B protein, comprising the steps of: contacting a transgenic mouse with a compound, wherein the cells of the transgenic mouse express a green fluorescent protein-FoxM1B (GFP-FoxM1B) fusion protein; administering growth hormone to the mouse; detecting localization of the GFP-FoxM1B protein in a cell that is removed from the mouse; and identifying a compound as a compound that inhibits FoxM1B nuclear localization if the GFP-FoxM1B protein is localized in the cytoplasm but not the nucleus of the cell that is removed from the mouse.

The invention also provides screening methods for identifying compounds that inhibit tumor cell proliferation comprising the steps of: expressing a FoxM1B reporter construct in a cell; and detecting FoxM1B activity in the presence and absence of a test compound. A suitable reporter construct is 6X FoxM1B/FoxA TATA-luciferase expression vector described in the Examples below.

In one aspect, a compound can be pre-selected for a screening method of the invention by contacting a plurality of cells with a candidate compound and assaying for cell proliferation, wherein a candidate compound is selected for a screening method of the invention if cell proliferation is inhibited (*i.e.* the cells proliferate more slowly or not at all in the presence than in the absence of the compound).

In addition, the invention provides methods for identifying compounds that can inhibit FoxM1B transcriptional activity or transformation of a cell, the methods comprising the steps of (a) assaying a cell for FoxM1B transcriptional activity, wherein the cell comprises a FoxM1B expression vector and a reporter gene construct comprising a FoxM1B-responsive transcription control element; and (b) assaying for FoxM1B

anchor independent growth by formation of colonies on soft agar using doxycycline inducible GFP-Foxm1b cell line. In preferred embodiments, the FoxM1B expression vector is CMV-FoxM1B cDNA expression vector. In preferred embodiments, the reporter gene is luciferase and the FoxM1B-responsive transcription control element
5 comprises the 6X FoxM1B binding site driving TATA box. In preferred embodiments, these constructs are co-transferred into the cell, either consecutively or simultaneously.

The invention also provides pharmaceutical compositions comprising compounds identified using any of the screening methods of the invention and methods of using the pharmaceutical compositions to inhibit tumor growth in animals. The invention further
10 provides pharmaceutical compositions comprising a peptide having an amino acid sequence as set forth in SEQ ID NO: 10, SEQ ID NO: 11, or SEQ ID NO: 12 or therapeutically-effective mixture thereof. In certain aspects, pharmaceutical compositions of the invention are useful for inhibiting tumor cell growth in an animal by inhibiting FoxM1B activity in the tumor cell.

15 Specific preferred embodiments of the invention will become evident from the following more detailed description of certain preferred embodiments and the claims.

DETAILED DESCRIPTION OF THE DRAWINGS

Figures 1A and 1B depict a human FoxM1B cDNA comprising a deletion of the
20 terminal 972 nucleotides at the 3' end (SEQ ID NO: 1).

Figure 1C depicts a human FoxM1B protein sequence (SEQ ID NO: 2) encoded by the nucleotide sequence as set forth in SEQ ID NO: 1.

Figure 2 is a schematic representation of triple-LoxP FoxM1B targeting vector used to generate conditional FoxM1B knockout mice.

Figures 3A and 3B show RNase protection assays (RPA) with a FoxM1B probe after infection of human hepatoma HepG2 cells with Adenovirus expressing antisense
5 human FoxM1B cDNA (AdFoxM1B AS).

Figures 4A and 4B show RNase protection assays (RPA) with a FoxM1B probe after infection of human osteoblastoma U2Os cells with AdFoxM1B AS.

Figure 5A shows the FoxM1B amino acid sequence from amino acid residue 582-662 (SEQ ID NO: 8) and the LXLXXL (SEQ ID NO: 3) motif, which extends from
10 amino acid residue 635-662 (SEQ ID NO: 9). All of the Thr or Ser residues in the FoxM1B protein sequence that are potential Cdk1/Cdk2 phosphorylation sites were changed to alanine and the Leu residue at 641 in the LXLXXL (SEQ ID NO: 3) motif was changed to alanine.

Figure 5B depicts a graph showing that mutation of the Cdk1 phosphorylation
15 site at 596 and Leu residue at 641 causes diminished FoxM1B transcriptional activity. Results are expressed as the percent activity with respect to wild-type FoxM1B where CMV-empty served as a control for basal expression levels of the FoxM1B reporter gene. Four separate transfection experiments were performed in triplicate to calculate \pm SD.

20 Figure 5C shows the results of Western blot analysis with T7 epitope-tagged antibody of U20S cells transiently transfected with CMV-GFP-T7-FoxM1B following immunoprecipitation with a Cdk1 or Cdk2 polyclonal antibody. The immunoprecipitated proteins were subjected to Western blot analysis using a

monoclonal antibody against the T7 epitope tagged antibody protein. These co-immunoprecipitation studies showed that the Leu residue at 641 was required for association with the Cdk-Cyclin complexes.

Figure 5D shows the results of a kinase assay of U20S cells transiently
5 transfected with CMV GFP-FoxM1B (lane1), CMV-GFP-FoxM1B T585A (lane 2),
CMV GFP-FoxM1B T596A (lane 3), CMV GFP-FoxM1B L641A (lane 4), or CMV
GFP-FoxM1BS657A (lane 5).

Figure 5E shows diminished *in vivo* phosphorylation of the FoxM1B T596A Cdk
mutant and FoxM1B L641A mutant proteins by the Cdk-Cyclin protein complexes.
10 U20S cells were transiently transfected with either CMV T7-FoxM1B, CMV T7-
FoxM1B T596A or FoxM1B L641A, and transfected cells were then serum starved for
48 hours. The cells were then incubated in the presence or absence of serum for 12 or
18 hours, the cells harvested and protein extracts prepared. Protein extracts were
immunoprecipitated (IP) with an antibody specific for the T7 epitope and then subjected
15 to Western blot analysis with MPM2 monoclonal antibody that recognizes
phosphorylated Cdk sites. Western blot analysis with T7 antibody demonstrated equal
amounts of FoxM1B protein in all the lanes. Relative intensity of MPM2 signal was
determined and FoxM1B levels from cells not stimulated with serum was set at one.

Figure 6A is a schematic diagram depicting inhibition of Cdk1 kinase activity by
20 either Myt1 phosphorylation, dominant-negative (DN) Cdk1 or the Cdk1 inhibitor
Alsterpaullone.

Figure 6B is a schematic diagram depicting stimulation of Cdk1 activity by
Cdc25B and Cdc25C dephosphorylation.

Figure 6C is a graph demonstrating that inhibition of Cdk1 activity diminished FoxM1B transcriptional activity in cotransfection assays. U20S TetR cells were transiently co-transfected with the reporter 6X-FoxM1B-TATA-Luciferase and CMV-TO-FoxM1B (500 ng) alone or with increasing amounts of either CMV-DN-Cdk1, Cdk1 pharmacological inhibitor Alsterpaullone or CMV-Myt1. Results are expressed as the percent activity with respect to wild-type FoxM1B using four separate transfection experiments were performed in triplicate to calculate \pm SD.

Figure 6D is a graph demonstrating that activation of Cdk1 activity by dephosphorylation with either Cdc25B or Cdc25C stimulated FoxM1B transcriptional activity, which was potentiated by increased CBP levels.

Figures 7A-H show nuclear localization of GFP-FoxM1B fusion protein following treatment with either pharmacological kinase inhibitors or dominant negative kinases. U20S cells were transiently transfected with CMV GFP-FoxM1B with the indicated pharmacological kinase inhibitors (B-D) or dominant-negative kinase expression vectors (E-H). Cells in panel (A) were untreated.

Figure 8A is a graph demonstrating that inhibition of CBP histone acetyl transferase activity by E1A decreased the FoxM1B transcriptional activity. U20S cells were transiently co-transfected with the reporter 6X-FoxM1B-TATA-Luciferase and CMV- FoxM1B alone or in different combinations with CBP and E1A expression vectors.

Figure 8B shows the results of Western blot analysis of cell lysates after immunoprecipitation with a monoclonal antibody that recognized CBP. U20S cells were transiently transfected with CBP and either CMV WT GFP-FoxM1B (lanes 1-2),

CMV GFP-FoxM1B L641A (lanes 3-4), CMV GFP-FoxM1B S657A (lanes 5-6), or mock transfected (lanes 7-8). The first lane of each set contains 1/10 of the input protein extract (50ug) and the second lane contains the immunoprecipitated (IP) protein extracts.

Figure 9A shows a schematic diagram depicting the
5 Ras/MEK/MAPK/p90Rsk/Myt1 and PI3K/PDK1/p90Rsk/Myt1 pathways, which prevent Myt1 phosphorylation mediated inhibition of Cdk1 activity. Also shown is the action of DN-RasN17, the MEK1/2 inhibitor U0126, PI3K inhibitor Ly294002, DN-Akt and Akt pharmacological kinase inhibitor and DN-p90Rsk.

Figure 9B shows the results of Western blot analysis with GFP antibody of
10 protein extracts from U2OS cells transiently transfected with CMV GFP-FoxM1B plasmid with either CMV DN-p90Rsk or CMV DN-RasN17 or 50 μ M of U0126, 50 μ M of PI3K inhibitor Ly294002 or 25 μ M of Akt inhibitor.

Figure 9C is a graph demonstrating that inhibition of Ras/MEK/MAPK/p90Rsk and PI3K/PDK1/p90Rsk pathways resulted in diminished FoxM1B transcriptional
15 activity. U2OS TetR cells were transiently co-transfected with the reporter 6X-FoxM1B-TATA-Luciferase and CMV-TO-FoxM1B (500 ng) with CMV-DN-p90Rsk, CMV-DN-Ras or DN-AKT or with 50 μ M of either U0126 or Ly294002 alone or together or with 25 μ M of Akt inhibitor. Four separate transfection experiments were performed in triplicate to calculate \pm SD.

20 Figures 10A-B show fluorescent micrographs of TUNEL assay (100 X) demonstrated similar apoptosis levels in Alb-Cre *Foxm1b* $-/-$ and *Foxm1b* fl/fl control after 23 weeks of DEN/PB exposure.

Figure 10C shows a graph of the number of apoptotic cells (TUNEL positive) per 1000 hepatocytes (\pm SD) in non-tumor regions of livers from male *Foxm1b* fl/fl or Alb-Cre *Foxm1b* *-/-* mice after either 0, 6, 23, or 33 weeks of DEN/PB exposure.

Figures 10D-G show high power magnification of hepatocytes in which the nuclei were counterstained with DAPI (630 X; D-E) or visualized by Laser Confocal microscopy (F-G; bar indicates 2 μ m). A centromere-specific mouse fluorescent *in situ* hybridization (FISH) probe was used to show that Alb-Cre *Foxm1b* *-/-* hepatocyte nuclei possessed an increase in the number of hybridizing chromosomes compared to control hepatocyte nuclei at 23 weeks of DEN/PB treatment.

Figure 10H is a graph of the mean number of DAPI stained hepatocyte nuclei per 200X field (\pm SD) in non-tumor regions of livers from male *Foxm1b* fl/fl or Alb-Cre *Foxm1b* *-/-* mice either untreated or after 6, 23, or 33 weeks of DEN/PB exposure. The mean number (\pm SD) of TUNEL or DAPI positive hepatocyte nuclei per 1000 cells or 200X field was calculated by counting the number of positive hepatocyte nuclei using 5 different liver sections from 3 male mice at the indicated times of DEN/PB exposure.

Figure 11A-H shows immunohistochemically stained liver sections from *Foxm1b* fl/fl and Alb-Cre *Foxm1b* *-/-* mice either untreated or treated with DEN/PB for either 6, 23 or 33 weeks stained for nuclear expression of FoxM1B protein. Abundant nuclear staining of FoxM1B protein was induced as early as 6 weeks after DEN/PB exposure in *Foxm1b* fl/fl hepatocytes surrounding the periportal vein (PV, C), but not in hepatocytes near the central vein (CV). High levels of nuclear FoxM1B protein persisted in hyper-proliferative hepatic adenomas and HCC (C and E, margins of tumor indicated by arrows). As expected, nuclear staining of Foxm1b protein was not found in Alb-Cre

Foxm1b ^{-/-} hepatocytes at any of the time points following DEN/PB treatment (B, D, F and H). Abbreviations are PV, portal vein and CV, central vein. Magnifications are 200X.

Figure 12A-I shows that Alb-Cre *Foxm1b* ^{-/-} livers exhibit normal expression of
5 GST-pi and CAR following DEN/PB treatment. Alb-Cre *Foxm1b* ^{-/-} and *Foxm1b* fl/fl
livers isolated from male mice after 23 weeks of DEN/PB exposure were
immunohistochemically stained with antibody specific to Glutathione-S-transferase
placental isoform (GST-pi). Both Alb-Cre *Foxm1b* ^{-/-} and *Foxm1b* fl/fl hepatocytes were
strongly immunostained for GST-pi after 23 weeks of DEN/PB treatment (C-F) but its
10 expression was not detected in untreated control *Foxm1b* fl/fl mouse liver (A-B).
Western blot analysis with liver protein extracts demonstrated that hepatic expression of
GST-pi protein was induced as early as 6 weeks following DEN/PB treatment and that its
hepatic expression continued following 23 weeks of DEN/PB exposure (G). Normal
hepatocyte nuclear levels of the CAR nuclear receptor were found in male Alb-Cre
15 *Foxm1b* ^{-/-} mice following DEN/PB treatment (H-I). Magnifications: A, C, E is 50X; B,
D, F, H, I is 200X.

Figures 13A-B show p27^{Kip1} immunohistochemical staining of liver sections from
untreated Alb-Cre *Foxm1b* ^{-/-} and *Foxm1b* fl/fl mice.

Figures 13C-J show immunohistochemical staining of liver sections from Alb-Cre
20 *Foxm1b* ^{-/-} and *Foxm1b* fl/fl male mice after either untreated or after 6, 23, or 33 weeks
of DEN/PB exposure to examine hepatocyte nuclear expression of p27^{Kip1} protein. In
Figure 13E and G, the margins of hepatic adenoma (Ad) or hepatocellular Carcinoma
(HCC) are indicated by arrows. Magnification: A-J is 200X.

Figure 13K shows immunohistochemical staining of p27^{Kip1} protein in female Alb-Cre *Foxm1b* ^{-/-} mice hepatocytes after 50 weeks DEN/PB treatment.

Figure 13L shows immunohistochemical staining of p27^{Kip1} protein in male Alb-Cre *Foxm1b* ^{-/-} mice hepatocytes after 50 weeks of DEN/PB.

5 Figures 13M-N show graphs of percent p27^{Kip1} positive hepatocyte nuclei per 200X field liver section during tumor progression. Number of hepatocyte nuclei per 200X section was determined by DAPI staining.

Figure 14A shows results from Western blot analysis of p27^{Kip1}, Cdc25B or Cdc25C protein expression in liver protein extracts isolated from either untreated or
10 DEN/PB treated mice. Expression levels of Cdk2 were used as a loading control.

Figure 14B is a drawing depicting the FoxM1B winged helix DNA binding domain (WHD), the C-terminal transcriptional activation domain (TAD), and the FoxM1B LXL motif (639-641) that recruits either the Cdk2-Cyclin E/A (S-phase) or Cdk1-Cyclin B (G2 phase) complexes.

15 Figure 14C shows co-immunoprecipitation (Co-IP) assays with protein extracts prepared from U2OS cells that were transiently transfected CMV p27^{Kip1} and with CMV expression vectors containing either WT GFP-FoxM1B or GFP-Foxm1b L641A mutant protein that fail to recruit the Cdk-Cyclin complexes. Also shown is a control lane containing 1/10 of the extract used in the Co-IP experiment.

20 Figure 14D shows that p27^{Kip1} protein inhibited FoxM1B transcriptional activity in cotransfection assays. Transfections were performed twice in triplicate and used to calculate percent WT FoxM1B transcriptional levels (±SD).

Figure 15A shows Western Blot analysis, blotting with a p19^{ARF} (p19) antibody, of liver extracts prepared from two mice following either no treatment or 6, 23 and 33 weeks of DEN/PB exposure. Expression levels of Cdk2 were used as a loading control.

Figure 15B shows co-immunoprecipitation (Co-IP) assays performed with liver protein extracts prepared from *Foxm1b* fl/fl and Alb-Cre *Foxm1b* ^{-/-} mice following either 6 or 23 weeks of DEN/PB treatment. The protein extracts were first immunoprecipitated with p19 antibody and then analyzed by Western blot analysis with a mouse FoxM1B antibody.

Figure 15C is a drawing depicting functional domains of the FoxM1B and p19^{ARF} tumor suppressor proteins. Schematically shown is the FoxM1B winged helix DNA binding domain (WHD), the C-terminal transcriptional activation domain (TAD) and the C-terminal region (688-748) required for p19^{ARF} (p19) binding. Schematically shown are the p19 nucleolar localization sequence (NrLS) and the p19 Mdm2 and FoxM1B binding sites.

Figure 15D shows co-IP assays with protein extracts prepared from U2OS cells that were transiently transfected with CMV green fluorescent protein (GFP)-FoxM1B fusion protein and with p19 expression vectors. These included expression vectors containing either WT p19 protein or N-terminal deletion mutants of the p19 protein (Δ 1-14, Δ 15-25, Δ 26-37, Δ 26-37 + Δ 1-14) that were fused with an hemagglutinin (HA) epitope tag. The p19 protein was immunoprecipitated from transfected protein extracts with HA antibody followed by Western blot analysis with a monoclonal antibody specific to the GFP protein to detect the GFP-FoxM1B fusion protein.

Figure 15E shows co-IP assays with protein extracts prepared from U2OS cells that were transiently transfected with CMV GFP-FoxM1B fusion protein and expression vector containing V5 epitope tagged p19^{ARF} 26-44 or p19^{ARF} 26-55 sequences. The p19 protein was immunoprecipitated from transfected protein extracts with V5 epitope antibody followed by Western blot analysis with GFP monoclonal antibody.

Figure 15F shows that the p19 protein inhibits FoxM1B transcriptional activity in cotransfection assays.

Figure 16A-D shows immunostaining of U2OS cells transfected with HA-p19^{ARF} and GFP- FoxM1B expression vectors demonstrating that the HA tagged p19 was able to target nuclear fluorescence of WT GFP-Foxm1b fusion protein (D) to the nucleolus (B, C).

Figures 16E-I shows nucleolar targeting of GFP- FoxM1B WT protein in cotransfections with CMV expression vectors containing mutant p19^{ARF} proteins (Δ 1-14, Δ 15-25, 26-44 or 26-55) that were still able to associate with FoxM1B protein.

Figure 16I shows nucleolar fluorescence of CMV GFP- p19^{ARF} 26-44.

Figure 16J shows nuclear fluorescence of CMV WT GFP- FoxM1B and expression vector containing mutant p19^{ARF} Δ 26-37 protein that failed to interact with FoxM1B.

Figure 16K shows transfection of CMV WT p19 expression vector was unable to elicit nucleolar targeting of GFP- FoxM1B 1-688 protein, which failed to bind to p19 protein.

Figure 16L shows that treatment of U2OS cells for three days with the TRITC fluorescently tagged (D-Arg)₉-p19^{ARF} 26-44 peptide demonstrated that this p19^{ARF} peptide was transduced into the cell and was localized to the nucleolus.

Figure 17A is a graph showing that the (D-Arg)₉-p19^{ARF} 26-44 peptide was an effective inhibitor of FoxM1B transcriptional activity.

Figure 17B is a Western blot analysis showing that the CMV-TETO GFP-Foxm1b U2OS clone C3 cell line displayed Doxycycline inducible expression of the GFP- FoxM1B fusion protein.

Figure 17C-H shows results of colony formation assays wherein the (D-Arg)₉-p19^{ARF} 26-44 peptide significantly diminished the ability of induced GFP- FoxM1B to stimulate colony formation of the U2OS clone C3 cells on soft agar. Doxycycline induced FoxM1B-GFP expression stimulated anchorage-independent growth in the U2OS clone C3 cell line (F-G) as assessed by propagation for two weeks on soft agar while the (D-Arg)₉-p19^{ARF} 26-44 peptide significantly inhibited colony formation of U2OS cells on soft agar (E and H).

Figure 17I shows a graph depicting quantitation of FoxM1B induced formation of U2OS cell colonies on soft agar treated or not treated with the (D-Arg)₉-p19^{ARF} 26-44 peptide. The number of U2OS colonies of the indicated treatments were counted in 4 to 5 different 100X fields and determined the mean number of cell colonies (±SD).

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Conventional techniques well known to those with skill in the art were used for recombinant DNA production, oligonucleotide synthesis, and tissue culture and cell

transformation (*e.g.*, electroporation, lipofection) procedures. Enzymatic reactions and purification techniques were performed according to manufacturers' specifications or as commonly accomplished in the art or as described herein. The techniques and procedures were generally performed according to conventional methods well known in the art and as described in various general and more specific references that are cited and discussed throughout the present specification. *See e.g.*, Sambrook *et al.*, 2001, MOLECULAR CLONING: A LABORATORY MANUAL, 3d ed., Cold Spring Harbor Laboratory Press, Cold Spring Harbor, N.Y., which is incorporated herein by reference for any purpose. Unless specific definitions are provided, the nomenclature utilized in connection with, and the laboratory procedures and techniques of, molecular biology, genetic engineering, analytical chemistry, synthetic organic chemistry, and medicinal and pharmaceutical chemistry described herein are those well known and commonly used in the art. Standard techniques can be used for chemical syntheses, chemical analyses, pharmaceutical preparation, formulation, and delivery, and treatment of patients.

Unless otherwise required by context, singular terms shall include pluralities and plural terms shall include the singular.

Definitions

As utilized in accordance with the present disclosure, the following terms, unless otherwise indicated, shall be understood to have the following meanings:

The term "isolated protein" referred to herein means a protein encoded by a nucleic acid including, *inter alia*, genomic DNA, cDNA, recombinant DNA, recombinant RNA, or nucleic acid of synthetic origin or some combination thereof, which (1) is free

of at least some proteins with which it would normally be found, (2) is essentially free of other proteins from the same source, *e.g.*, from the same cell or species, (3) is expressed by a cell from a different species, (4) has been separated from at least about 50 percent of polynucleotides, lipids, carbohydrates, or other materials with which it is naturally found
5 when isolated from the source cell, (5) is not linked (by covalent or noncovalent interaction) to all or a portion of a polypeptide to which the “isolated protein” is linked in nature, (6) is operatively linked (by covalent or noncovalent interaction) to a polypeptide with which it is not linked in nature, or (7) does not occur in nature. Preferably, the isolated protein is substantially free from other contaminating proteins or polypeptides or
10 other contaminants that are found in its natural environment that would interfere with its therapeutic, diagnostic, prophylactic or research use.

The terms “polypeptide” or “protein” is used herein to refer to native proteins, that is, proteins produced by naturally-occurring and specifically non-recombinant cells, or by genetically-engineered or recombinant cells, and comprise molecules having the
15 amino acid sequence of the native protein, or sequences that have deletions, additions, and/or substitutions of one or more amino acids of the native sequence. The terms “polypeptide” and “protein” specifically encompass FoxM1B protein, or species thereof that have deletions, additions, and/or substitutions of one or more amino acids of FoxM1B having at least one functional property of the FoxM1B protein. In addition, the
20 terms “polypeptide” and “protein” specifically encompass peptides that can inhibit FoxM1B activity, including the (D-Arg)₉-p19ARF 26-44 peptide (SEQ ID NO: 10; `rrrrrrrrKFVRSRRPRTASCALAFVN`), the p19^{ARF} 26-44 peptide (SEQ ID NO: 11; `KFVRSRRPRTASCALAFVN`), and the p19^{ARF} 26-55 peptide (SEQ ID NO: 12;

KFVRSRRPRTASCALAFVNMLLRRLRR), or species thereof that have deletions, additions, and/or substitutions of one or more amino acids of SEQ ID NO: 10, SEQ ID NO: 11, or SEQ ID NO: 12 having the ability to inhibit FoxM1B activity.

The term “naturally-occurring” as used herein refers to an object that can be found in nature, *for example*, a polypeptide or polynucleotide sequence that is present in an organism (including a virus) that can be isolated from a source in nature and which has not been intentionally modified by man. The term “naturally occurring” or “native” when used in connection with biological materials such as nucleic acid molecules, polypeptides, host cells, and the like, refers to materials which are found in nature and are not manipulated by man. Similarly, “recombinant,” “non-naturally occurring” or “non-native” as used herein refers to a material that is not found in nature or that has been structurally modified or synthesized by man.

As used herein, the twenty conventional amino acids and their abbreviations follow conventional usage. See IMMUNOLOGY--A SYNTHESIS, 2nd Edition, (E. S. Golub and D. R. Gren, Eds.), 1991, Sinauer Associates, Sunderland, Mass., which is incorporated herein by reference for any purpose. According to certain embodiments, single or multiple amino acid substitutions (in certain embodiments, conservative amino acid substitutions) may be made in the naturally-occurring sequence (in certain embodiments, in the portion of the polypeptide outside the domain(s) forming intermolecular contacts or comprising functional domains). In certain embodiments, a conservative amino acid substitution does not substantially change the structural characteristics of the parent sequence (*e.g.*, a replacement amino acid should not disrupt secondary structure that characterizes the parent or native protein, such as a helix).

Examples of art-recognized polypeptide secondary and tertiary structures are described in PROTEINS, STRUCTURES AND MOLECULAR PRINCIPLES (Creighton, Ed.), 1984, W. H. New York: Freeman and Company; INTRODUCTION TO PROTEIN STRUCTURE (Branden and Tooze, eds.), 1991, New York: Garland Publishing; and
5 Thornton *et al.*, 1991, *Nature* 354: 105, which are each incorporated herein by reference.

Naturally occurring residues may be divided into classes based on common side chain properties: 1) hydrophobic: norleucine, Met, Ala, Val, Leu, Ile; 2) neutral hydrophilic: Cys, Ser, Thr, Asn, Gln; 3) acidic: Asp, Glu; 4) basic: His, Lys, Arg; 5) residues that influence chain orientation: Gly, Pro; and 6) aromatic: Trp, Tyr, Phe.

10 Conservative amino acid substitutions may encompass non-naturally occurring amino acid residues, which are typically incorporated by chemical peptide synthesis rather than by synthesis in biological systems. These include peptidomimetics and other reversed or inverted forms of amino acid moieties.

In contrast, non-conservative substitutions may involve the exchange of a member
15 of one of these classes for a member from another class. Such substituted residues may be introduced into regions of a protein or polypeptide that are homologous with non-human orthologs thereof, or into the non-homologous regions of the molecule.

In making such changes, according to certain embodiments, the hydropathic index of amino acids may be considered. Each amino acid has been assigned a hydropathic
20 index on the basis of its hydrophobicity and charge characteristics. They are: isoleucine (+4.5); valine (+4.2); leucine (+3.8); phenylalanine (+2.8); cysteine/cystine (+2.5); methionine (+1.9); alanine (+1.8); glycine (-0.4); threonine (-0.7); serine (-0.8); tryptophan (-0.9); tyrosine (-1.3); proline (-1.6); histidine (-3.2); glutamate (-3.5);

glutamine (-3.5); aspartate (-3.5); asparagine (-3.5); lysine (-3.9); and arginine (-4.5) (Kyte *et al.*, 1982, *J. Mol. Biol.* 157:105-131).

The importance of the hydropathic amino acid index in conferring interactive biological function on a protein is understood in the art (see, *for example*, Kyte *et al.*, 1982, *ibid.*). It is known that certain amino acids may be substituted for other amino acids having a similar hydropathic index or score and still retain a similar biological activity. In making changes based upon the hydropathic index, in certain embodiments, the substitution of amino acids whose hydropathic indices are within ± 2 is included. In certain embodiments, those that are within ± 1 are included, and in certain embodiments, those within ± 0.5 are included.

It is also understood in the art that the substitution of like amino acids can be made effectively on the basis of hydrophilicity, particularly where the biologically functional protein or peptide thereby created is intended for use in immunological embodiments, as in the present case. In certain embodiments, the greatest local average hydrophilicity of a protein, as governed by the hydrophilicity of its adjacent amino acids, correlates with its immunogenicity and antigen-binding or immunogenicity, *i.e.*, with a biological property of the protein.

As described in U.S. Patent No. 4,554,101, the following hydrophilicity values have been assigned to these amino acid residues: arginine (+3.0); lysine (+3.0); aspartate (+3.0 \pm 1); glutamate (+3.0 \pm 1); serine (+0.3); asparagine (+0.2); glutamine (+0.2); glycine (0); threonine (-0.4); proline (-0.5 \pm 1); alanine (-0.5); histidine (-0.5); cysteine (-1.0); methionine (-1.3); valine (-1.5); leucine (-1.8); isoleucine (-1.8); tyrosine (-2.3); phenylalanine (-2.5) and tryptophan (-3.4). In making changes based upon similar

hydrophilicity values, in certain embodiments, the substitution of amino acids whose hydrophilicity values are within ± 2 is included, in certain embodiments, those that are within ± 1 are included, and in certain embodiments, those within ± 0.5 are included.

Exemplary amino acid substitutions are set forth in Table 1.

5

Table 1

Amino Acid Substitutions

Original Residues	Exemplary Substitutions	Preferred Substitutions
Ala	Val, Leu, Ile	Val
Arg	Lys, Gln, Asn	Lys
Asn	Gln	Gln
Asp	Glu	Glu
Cys	Ser, Ala	Ser
Gln	Asn	Asn
Glu	Asp	Asp
Gly	Pro, Ala	Ala
His	Asn, Gln, Lys, Arg	Arg
Ile	Leu, Val, Met, Ala, Phe, Norleucine	Leu
Leu	Norleucine, Ile, Val, Met, Ala, Phe	Ile
Lys	Arg, Gln, Asn, 1,4 Diamine-butyric Acid	Arg
Met	Leu, Phe, Ile	Leu
Phe	Leu, Val, Ile, Ala, Tyr	Leu
Pro	Ala	Gly
Ser	Thr, Ala, Cys	Thr
Thr	Ser	Ser
Trp	Tyr, Phe	Tyr
Tyr	Trp, Phe, Thr, Ser	Phe
Val	Ile, Met, Leu, Phe, Ala, Norleucine	Leu

A skilled artisan can determine suitable variants of the polypeptide as set forth herein using well-known techniques. In certain embodiments, one skilled in the art can identify suitable areas of the molecule that can be changed without destroying activity by targeting regions not believed to be important for activity. In certain embodiments, one

can identify residues and portions of the molecules that are conserved among similar polypeptides. In certain embodiments, even areas that are important for biological activity or for structure can be subject to conservative amino acid substitutions without destroying the biological activity or without adversely affecting the polypeptide structure.

5 Additionally, one skilled in the art can review structure-function studies identifying residues in similar polypeptides that are important for activity or structure. In view of such a comparison, one can predict the importance of amino acid residues in a protein that correspond to amino acid residues important for activity or structure in similar proteins. One skilled in the art may opt for chemically similar amino acid
10 substitutions for such predicted important amino acid residues.

One skilled in the art can also analyze the three-dimensional structure and amino acid sequence in relation to that structure in similar polypeptides. In view of such information, one skilled in the art can predict the alignment of amino acid residues of a polypeptide with respect to its three dimensional structure. In certain embodiments, one
15 skilled in the art may choose not to make radical changes to amino acid residues predicted to be on the surface of the protein, since such residues may be involved in important interactions with other molecules. Moreover, one skilled in the art may generate test variants containing a single amino acid substitution at each desired amino acid residue. The variants can then be screened using activity assays known to those
20 skilled in the art. Such variants can be used to gather information about suitable variants. For example, if it was discovered that a change to a particular amino acid residue resulted in destroyed, undesirably reduced, or unsuitable activity, variants with such a change can be avoided. In other words, based on information gathered from such routine

experiments, one skilled in the art can readily determine the amino acids where further substitutions should be avoided either alone or in combination with other mutations.

Stereoisomers (*e.g.*, D-amino acids) of the twenty conventional amino acids, non-naturally occurring amino acids such as α,α -disubstituted amino acids, N-alkyl amino acids, lactic acid, and other unconventional amino acids may also be suitable components for polypeptides of the present invention. Examples of unconventional amino acids include but are not limited to: 4-hydroxyproline, γ -carboxyglutamate, ϵ -N,N,N-trimethyllysine, ϵ -N-acetyllysine, O-phosphoserine, N-acetylserine, N-formylmethionine, 3-methylhistidine, 5-hydroxylysine, σ -N-methylarginine, and other similar amino acids and imino acids (*e.g.*, 4-hydroxyproline). In the polypeptide notation used herein, the left-hand direction is the amino terminal direction and the right-hand direction is the carboxy-terminal direction, in accordance with standard usage and convention.

Peptide analogs are commonly used in the pharmaceutical industry as non-peptide drugs with properties analogous to those of the template peptide. These types of non-peptide compound are termed "peptide mimetics" or "peptidomimetics." (*See* Fauchere, 1986, *Adv. Drug Res.* 15: 29; Veber and Freidinger, 1985, *TINS* p.392; and Evans *et al.*, 1987, *J. Med. Chem.* 30: 1229, which are incorporated herein by reference for any purpose.) Such compounds are often developed with the aid of computerized molecular modeling. Peptide mimetics that are structurally similar to therapeutically useful peptides may be used to produce a similar therapeutic or prophylactic effect. Generally, peptidomimetics are structurally similar to a paradigm polypeptide (*i.e.*, a polypeptide that has a biochemical property or pharmacological activity), but have one or more peptide linkages optionally replaced by a linkage such as: --CH₂NH--, --CH₂S--, --CH₂-

CH₂ --, --CH=CH-- (*cis* and *trans*), --COCH₂--, --CH(OH)CH₂--, and --CH₂SO--, by methods well known in the art. Systematic substitution of one or more amino acids of a consensus sequence with a D-amino acid of the same type (e.g., D-lysine in place of L-lysine) may be used in certain embodiments to generate more stable peptides. In addition, conformationally-constrained peptides comprising a consensus sequence or a substantially identical consensus sequence variation may be generated by methods known in the art (Rizo and Gierasch, 1992, *Ann. Rev. Biochem.* 61: 387), incorporated herein by reference for any purpose); for example, by adding internal cysteine residues capable of forming intramolecular disulfide bridges which cyclize the peptide.

As used herein, the term “isolated polynucleotide” as used herein means a polynucleotide of genomic, cDNA, or synthetic origin or a combination thereof, which by virtue of its source the “isolated polynucleotide” (1) is not associated with all or a portion of a polynucleotide in which the “isolated polynucleotide” is found in nature, (2) is linked to a polynucleotide which it is not linked to in nature, or (3) does not occur in nature as part of a larger sequence.

Unless specified otherwise, the left-hand end of single-stranded polynucleotide sequences is the 5' end; the left-hand direction of double-stranded polynucleotide sequences is referred to as the 5' direction. The direction of 5' to 3' addition of nascent RNA transcripts is referred to as the transcription direction; sequence regions on the DNA strand having the same sequence as the RNA and which are 5' to the 5' end of the RNA transcript are referred to as “upstream sequences”; sequence regions on the DNA strand having the same sequence as the RNA and which are 3' to the 3' end of the RNA transcript are referred to as “downstream sequences”.

The term “polynucleotide” as used herein means a polymeric form of nucleotides that are at least 10 bases in length. In certain embodiments, the bases may be ribonucleotides or deoxyribonucleotides or a modified form of either type of nucleotide. The term includes single and double stranded forms of DNA.

5 The term “oligonucleotide” as used herein includes naturally occurring, and modified nucleotides linked together by naturally occurring, and/or non-naturally occurring oligonucleotide linkages. Oligonucleotides are a polynucleotide subset generally comprising no more than 200 nucleotides. In certain embodiments, oligonucleotides are 10 to 60 nucleotides in length. In certain embodiments,
10 oligonucleotides are 12, 13, 14, 15, 16, 17, 18, 19, or 20 to 40 bases in length. Oligonucleotides are single stranded, *e.g.* for use in the construction of a gene mutant using site directed mutagenesis techniques. Oligonucleotides of the invention may be sense or antisense oligonucleotides.

 The term “naturally occurring nucleotides” includes deoxyribonucleotides and
15 ribonucleotides. The term “modified nucleotides” includes nucleotides with modified or substituted sugar groups and the like. The term “oligonucleotide linkages” includes oligonucleotides linkages such as phosphate, phosphorothioate, phosphorodithioate, phosphoroselenoate, phosphorodiselenoate, phosphoroanilothioate, phoshoraniladate, phosphoroamidate, and the like. *See, e.g., LaPlanche et al., 1986, Nucl. Acids Res.* 14:
20 9081; *Stec et al., 1984, J. Am. Chem. Soc.* 106: 6077; *Stein et al., 1988, Nucl. Acids Res.* 16: 3209; *Zon et al., 1991, Anti-Cancer Drug Design* 6: 539; *Zon et al., 1991, OLIGONUCLEOTIDES AND ANALOGUES: A PRACTICAL APPROACH*, (F. Eckstein, ed.), Oxford University Press, Oxford England, pp. 87-108; *Stec et al., U.S.*

Pat. No. 5,151,510; Uhlmann and Peyman, 1990, *Chemical Reviews* 90: 543, the disclosures of each of which are hereby incorporated by reference for any purpose. An oligonucleotide can include a detectable label, such as a radiolabel, a fluorescent label, an antigenic label or a hapten.

5 The phrase “recombinant nucleic acid construct” as used herein refers to a DNA or RNA sequence that comprises a coding sequence that is operatively linked to a control sequence. A recombinant nucleic acid construct of the invention is capable of expressing a protein that is encoded by the coding sequence when introduced into a cell. A recombinant nucleic acid construct of the invention preferably comprises the nucleic acid
10 sequence that encodes a protein as set forth in SEQ ID NO: 2, such as the nucleic acid sequence as set forth in SEQ ID NO: 1, whereby a cell contacted with the recombinant nucleic acid construct expresses FoxM1B protein. The term “operatively linked” as used herein refers to components that are in a relationship permitting them to function in their intended or conventional manner. For example, a control sequence “operatively linked”
15 to a coding sequence is ligated thereto in such a way that expression of the coding sequence is achieved under conditions compatible with the control sequences.

 The term “control sequence” or “control element” as used herein refers to polynucleotide sequences that can effect the expression and processing of coding sequences to which they are ligated. The nature of such control sequences may differ
20 depending upon the host organism. According to certain embodiments, control sequences for prokaryotes may include promoters, repressors, operators, ribosomal binding sites, and transcription termination sequences and antisense mRNA. According to certain embodiments, control sequences for eukaryotes may include promoters,

enhancers and transcription termination sequences, or sequences that regulate protein degradation, mRNA degradation, nuclear localization, nuclear export, cytoplasmic retention, protein phosphorylation, protein acetylation, protein sumolation, or RNA inhibition (RNAi). In certain embodiments, “control sequences” can include leader
5 sequences and/or fusion partner sequences. “Control sequences” are “operatively linked” to a coding sequence when the “control sequence” effects expression and processing of coding sequences to which they are ligated. In one embodiment, a control sequence or control element can be a FoxM1B-responsive transcription control element that comprises the 6X FoxM1B binding site driving TATA box, as described in the Examples
10 below.

As used herein, the phrase “tissue specific promoters” refers to nucleic acid sequences that are capable of directing transcription of a coding sequence and that are activated specifically within a specific cell type. For example, liver specific promoters that drive expression of genes in liver cells include, but are not limited to, human or
15 mouse α 1-antitrypsin, albumin promoter, serum amyloid A, transthyretin, hepatocyte nuclear factor 6, and major urinary protein (MUP).

The term “vector” is used to refer to any molecule (*e.g.*, nucleic acid, plasmid, or virus) used to transfer coding information to a host cell or a target cell. Viral vectors suitable for the methods of the invention include those derived from, for example, an
20 adenovirus, an adeno-associated virus, a retrovirus, a herpes simplex virus, or a vaccinia virus.

The term “expression vector” refers to a vector that is suitable for transformation of a host cell or a target cell and contains nucleic acid sequences that direct and/or control

the expression of inserted heterologous nucleic acid sequences. Expression includes, but is not limited to, processes such as transcription, translation, and RNA splicing, if introns are present. In one embodiment, an expression vector of the invention is a CMV-FoxM1B cDNA, as described in the Examples below.

5 The term “host cell” is used to refer to a cell into which has been introduced, or that is capable of having introduced, a nucleic acid sequence and then of expressing a gene of interest. The term includes the progeny of the parent cell, whether or not the progeny is identical in morphology or in genetic make-up to the original parent, so long as the gene is present. In preferred embodiments, the host cell is a eukaryotic cell, more
10 preferably a mammalian cell and most preferably a rodent or human cell.

 The term “transduction” is used to refer to the transfer of genes from one bacterium to another, usually by a phage. “Transduction” also refers to the acquisition and transfer of eukaryotic cellular sequences by viruses such as retroviruses.

 The term “transfection” is used to refer to the uptake of foreign or exogenous
15 DNA by a cell, and a cell has been “transfected” when the exogenous DNA has been introduced inside the cell membrane. A number of transfection techniques are well known in the art and are disclosed herein. *See, e.g.,* Graham *et al.*, 1973, *Virology* 52: 456; Sambrook *et al.*, 2001, *MOLECULAR CLONING: A LABORATORY MANUAL*, 3d ed., Cold Spring Harbor Laboratory Press, Cold Spring Harbor, N.Y.; Davis *et al.*, 1986,
20 *BASIC METHODS IN MOLECULAR BIOLOGY* (Elsevier); and Chu *et al.*, 1981, *Gene* 13: 197. Such techniques can be used to introduce one or more exogenous DNA moieties into suitable host cells.

The term “transformation” as used herein refers to a change in a cell’s genetic characteristics, and a cell has been transformed when it has been modified to contain a new DNA. For example, a cell is transformed where it is genetically modified from its native state. Following transfection or transduction, the transforming DNA may
5 recombine with that of the cell by physically integrating into a chromosome of the cell, may be maintained transiently as an episomal element without being replicated, or may replicate independently as a plasmid. A cell is stably transformed when the DNA is replicated with the division of the cell.

In certain embodiments, methods of the invention comprise the step of expressing
10 FoxM1B protein in a host cell or a target cell by introducing into the cell a recombinant nucleic acid construct of the invention. According to such embodiments, the cells are transformed with the recombinant nucleic acid construct using any method for introducing polynucleotides into a host cell or a target cell, including, for example packaging the polynucleotide in a virus (or into a viral vector) and transducing a host cell
15 or a target cell with the virus (or vector), or by transfection procedures known in the art, as exemplified by U.S. Pat. Nos. 4,399,216, 4,912,040, 4,740,461, and 4,959,455 (which patents are hereby incorporated herein by reference for any purpose). In certain embodiments, the transformation procedure used may depend upon the cell to be transformed. Methods for introduction of heterologous polynucleotides into mammalian
20 cells are well known in the art and include, but are not limited to, dextran-mediated transfection, calcium phosphate precipitation, polybrene mediated transfection, protoplast fusion, electroporation, encapsulation of the polynucleotide(s) in liposomes, mixing

nucleic acid with positively-charged lipids, and direct microinjection of the DNA into cells and cell nuclei.

Recombinant nucleic acid constructs of the invention typically comprise a nucleic acid molecule encoding all or a functional portion of the amino acid sequence of FoxM1B protein that is inserted into an appropriate expression vector using conventional recombinant genetic techniques. Preferably, the recombinant nucleic acid construct of the invention comprises the nucleic acid sequence that encodes a protein as set forth in SEQ ID NO: 2. The vector is typically selected to be functional in the particular host cell or target cell employed (*i.e.*, the vector is compatible with the host cell or the target cell machinery, permitting amplification and/or expression of the gene). For a review of expression vectors, *see* Nolan and Shatzman, 1998, *Curr. Opin. Biotechnol.* 9:447-450.

Typically, expression vectors used in any of the host cells or target cells contain sequences for vector maintenance and for cloning and expression of exogenous nucleotide sequences. Such sequences, collectively referred to as “flanking sequences” in certain embodiments will typically include one or more of the following nucleotide sequences: a promoter, one or more enhancer sequences, an origin of replication, a transcriptional termination sequence, a complete intron sequence containing a donor and acceptor splice site, a sequence encoding a leader sequence for polypeptide secretion, a ribosome binding site, a polyadenylation signal sequence, a polylinker region comprising one or a plurality of restriction endonuclease sites for inserting nucleic acid encoding the polypeptide to be expressed, and a selectable marker element. Each of these sequences is discussed below.

Flanking sequences may be homologous (*i.e.*, from the same species and/or strain as the host cell or the target cell), heterologous (*i.e.*, from a species other than the host cell or the target cell species or strain), hybrid (*i.e.*, a combination of flanking sequences from more than one source), synthetic or native. As such, the source of a flanking
5 sequence may be any prokaryotic or eukaryotic organism, any vertebrate or invertebrate organism, or any plant, provided that the flanking sequence is functional in, and can be activated by, the host cell or the target cell machinery.

Flanking sequences useful in the vectors of this invention may be obtained by any of several methods well known in the art. Typically, flanking sequences useful herein
10 will have been previously identified by mapping and/or by restriction endonuclease digestion and can thus be isolated from the proper tissue source using the appropriate restriction endonucleases. In some cases, the full nucleotide sequence of a flanking sequence may be known. The flanking sequence also may be synthesized using the methods described herein for nucleic acid synthesis or cloning.

15 Where all or only a portion of the flanking sequence is known, it may be obtained using *in vitro* amplification methods such as polymerase chain reaction (PCR) and/or by screening a genomic library with a suitable oligonucleotide and/or flanking sequence fragment from the same or another species. Where the flanking sequence is not known, a fragment of DNA containing a flanking sequence may be isolated from a larger piece of
20 DNA that may contain, for example, a coding sequence or even another gene or genes. Isolation may be accomplished by restriction endonuclease digestion to produce the proper DNA fragment followed by isolation using agarose gel purification, Qiagen® column chromatography (Chatsworth, CA), or other methods known to the skilled

artisan. The selection of suitable enzymes to accomplish this purpose is readily apparent to one of ordinary skill in the art.

Optionally, the vector may contain a “tag”-encoding sequence, *i.e.*, an oligonucleotide molecule located at the 5’ or 3’ end of the FoxM1B polypeptide coding sequence, wherein such an oligonucleotide sequence encodes polyHis (such as hexaHis), or another “tag” for which commercially available antibodies exist, such as FLAG, HA (hemagglutinin influenza virus), or *myc*. This tag oligonucleotide is typically ligated to the coding sequence “in frame” so that the tag is fused to the polypeptide upon expression of the polypeptide, and can serve as a means for affinity purification of the FoxM1B polypeptide from the host cell or the target cell. Affinity purification can be accomplished, for example, by column chromatography using antibodies against the tag as an affinity matrix. Optionally, the tag can subsequently be removed from the purified FoxM1B polypeptide by various means such as using certain peptidases for cleavage. In preferred embodiments of such vectors permitting removal of the tag, a protease cleavage site is included in the tag sequence in a position between the tag and polypeptide amino acid sequences when the tagged polypeptide is expressed.

In some cases, for example where glycosylation is desired in a eukaryotic host cell expression system, various presequences can be manipulated to improve glycosylation or yield. For example, the peptidase cleavage site of a particular signal peptide can be altered, or pro-sequences added, which also may affect glycosylation. The final protein product may have, in the -1 position (relative to the first amino acid of the mature protein) one or more additional amino acids incident to expression, which may not have been totally removed. For example, the final protein product may have one or

two amino acid residues found in the peptidase cleavage site, attached to the amino-terminus. Alternatively, use of some enzyme cleavage sites may result in a slightly truncated yet active form of the desired polypeptide, if the enzyme cuts at such area within the mature polypeptide.

5 A transcription termination sequence is typically located 3' to the end of a polypeptide-coding region and serves to terminate transcription. Usually, a transcription termination sequence in prokaryotic cells is a G-C rich fragment followed by a poly-T sequence. While the sequence is easily cloned from a library or even purchased commercially as part of a vector, it can also be readily synthesized using methods for
10 nucleic acid synthesis such as those described herein. In eukaryotes, the sequence AAUAAA (SEQ ID NO: 7) functions both as a transcription termination signal and as a poly A signal required for endonuclease cleavage followed by the addition of poly A residues (usually consisting of about 200 A residues).

 A selectable marker gene element encodes a protein necessary for the survival
15 and growth of a host cell or a target cell grown in a selective culture medium. Typical selection marker genes encode proteins that (a) confer resistance to antibiotics or other toxins, *e.g.*, ampicillin, tetracycline, or kanamycin for prokaryotic host cells; (b) complement auxotrophic deficiencies of the cell; or (c) supply critical nutrients not available from complex media. Preferred selectable markers are the kanamycin
20 resistance gene, the ampicillin resistance gene, and the tetracycline resistance gene. A bacterial neomycin resistance gene can also be used most advantageously for selection in both prokaryotic and eukaryotic cells.

The expression and cloning vectors of the present invention will typically contain a promoter that is recognized by the host organism and operatively linked to nucleic acid encoding the FoxM1B protein. Promoters are untranscribed sequences located upstream (*i.e.*, 5') to the start codon of a structural gene (generally within about 100 to 1000 bp) that control transcription of the structural gene. Promoters are conventionally grouped into one of two classes: inducible promoters and constitutive promoters. Inducible promoters initiate increased levels of transcription from DNA under their control in response to some change in culture conditions, such as the presence or absence of a nutrient or a change in temperature. Constitutive promoters, on the other hand, initiate continual gene product production; that is, there is little or no experimental control over gene expression. A large number of promoters, recognized by a variety of potential host cells or target cells, are well known. A suitable promoter is operatively linked to the DNA encoding FoxM1B protein by removing the promoter from the source DNA by restriction enzyme digestion or amplifying the promoter by polymerase chain reaction and inserting the desired promoter sequence into the vector.

Suitable promoters for use with mammalian cells are well known and include, but are not limited to, those obtained from the genomes of eukaryotic viruses such as polyoma virus, fowlpox virus, adenovirus (such as Adenovirus 2), bovine papilloma virus, avian sarcoma virus, cytomegalovirus, retroviruses, hepatitis-B virus and most preferably Simian Virus 40 (SV40). Other suitable mammalian promoters include heterologous mammalian promoters, for example, heat-shock promoters and the actin promoter.

Particular promoters useful in the practice of the recombinant expression vectors of the invention include, but are not limited to: the SV40 early promoter region (Bernoist and Chambon, 1981, *Nature* 290: 304-10); the CMV promoter; the promoter contained in the 3' long terminal repeat of Rous sarcoma virus (Yamamoto, *et al.*, 1980, *Cell* 22: 787-97); the herpes thymidine kinase promoter (Wagner *et al.*, 1981, *Proc. Natl. Acad. Sci. U.S.A.* 78: 1444-45); and the regulatory sequences of the metallothionine gene (Brinster *et al.*, 1982, *Nature* 296: 39-42). Also of interest are the following animal transcriptional control regions, which exhibit tissue specificity and have been utilized in transgenic animals: the elastase I gene control region that is active in pancreatic acinar cells (Swift *et al.*, 1984, *Cell* 38: 639-46; Ornitz *et al.*, 1986, *Cold Spring Harbor Symp. Quant. Biol.* 50: 399-409; MacDonald, 1987, *Hepatology* 7: 425-515); the insulin gene control region that is active in pancreatic beta cells (Hanahan, 1985, *Nature* 315: 115-22); the mouse mammary tumor virus control region that is active in testicular, breast, lymphoid and mast cells (Leder *et al.*, 1986, *Cell* 45: 485-95); the beta-globin gene control region that is active in myeloid cells (Mogram *et al.*, 1985, *Nature* 315: 338-40; Kollias *et al.*, 1986, *Cell* 46: 89-94); the myelin basic protein gene control region that is active in oligodendrocyte cells in the brain (Readhead *et al.*, 1987, *Cell* 48: 703-12); the myosin light chain-2 gene control region that is active in skeletal muscle (Sani, 1985, *Nature* 314: 283-86); the gonadotropic releasing hormone gene control region that is active in the hypothalamus (Mason *et al.*, 1986, *Science* 234: 1372-78); and most particularly the immunoglobulin gene control region that is active in lymphoid cells (Grosschedl *et al.*, 1984, *Cell* 38: 647-58; Adames *et al.*, 1985, *Nature* 318: 533-38; Alexander *et al.*, 1987, *Mol. Cell Biol.* 7: 1436-44).

Preferably, the promoter of a recombinant nucleic acid construct of the invention is active in the tissue from which a target or host cell is derived. For example, if the cell is a liver cell, one could advantageously use the albumin gene control region (Pinkert *et al.*, 1987, *Genes and Devel.* 1: 268-76); the alpha-feto-protein gene control region (Krumlauf *et al.*, 1985, *Mol. Cell Biol.* 5: 1639-48; Hammer *et al.*, 1987, *Science* 235: 53-58); or the alpha 1-antitrypsin gene control region (Kelsey *et al.*, 1987, *Genes and Devel.* 1: 161-71), all of which are active in the liver.

The vectors of the invention can also contain an enhancer sequence that increases transcription in higher eukaryotic cells of nucleic acid encoding FoxM1B protein. Enhancers are *cis*-acting elements of DNA, are usually about 10-300 bp in length, and act on promoters to increase transcription. Enhancers are relatively orientation- and position-independent. They have been found within introns as well as within several kilobases both 5' and 3' to the transcription unit. Several enhancer sequences available from mammalian genes are known (*e.g.*, enhancers from globin, elastase, albumin, alpha-feto-protein, insulin, transthyretin, and HNF-6 genes). An enhancer from a virus also can be used to increase expression of a gene. The SV40 enhancer, the cytomegalovirus early promoter enhancer, the polyoma enhancer, and adenovirus enhancers are exemplary enhancing elements for the activation of eukaryotic promoters. While an enhancer may be spliced into the vector at a position 5' or 3' to a nucleic acid molecule, it is typically located at a site 5' from the promoter.

An origin of replication is typically a part of prokaryotic expression vectors, particularly those that are commercially available, and the origin aids in replication and amplification of the vector in a host cell or a target cell. If the vector of choice does not

contain an origin of replication site, one may be chemically synthesized based on a known sequence, and ligated into the vector. For example, the origin of replication from the plasmid pBR322 (New England Biolabs, Beverly, MA) is suitable for most gram-negative bacteria, and various replication origins (*e.g.*, from viruses of eukaryotes such as SV40, polyoma, adenovirus, vesicular stomatitis virus (VSV), or papillomaviruses such as HPV or BPV) are useful for cloning vectors in mammalian cells. Generally, a mammalian origin of replication is not needed for mammalian expression vectors (for example, the SV40 origin is often used only because it also contains the early promoter).

Expression vectors of the invention may be constructed from a convenient starting vector such as a commercially available vector. Such vectors may or may not contain all of the desired flanking sequences. Where one or more of the flanking sequences described herein are not already present in the vector, they may be individually obtained and ligated into the vector. Methods used for obtaining each of the flanking sequences are well known to one skilled in the art.

After the vector has been constructed and a nucleic acid molecule encoding FoxM1B protein has been inserted into the proper site of the vector, the completed vector may be inserted into a suitable host cell or a target cell for amplification and/or polypeptide expression. The transformation of an expression vector encoding FoxM1B protein into a selected host cell or target cell may be accomplished by well-known methods including methods such as transfection, infection, calcium chloride, electroporation, microinjection, lipofection, DEAE-dextran method, or other known techniques as described above. The method selected will in part be a function of the type of host cell or target cell to be used. These methods and other suitable methods are well

known to the skilled artisan, and are set forth, for example, in Sambrook *et al.*, 2001, MOLECULAR CLONING: A LABORATORY MANUAL, 3d ed., Cold Spring Harbor Laboratory Press, Cold Spring Harbor, N.Y.

5 A host cell or target cell, when cultured under appropriate conditions, synthesizes a FoxM1B protein that can subsequently be collected from the culture medium (if the host cell or target cell secretes it into the medium) or directly from the host cell or target cell producing it (if it is not secreted) if collection of the protein is desired. Selection of an appropriate host cell will depend upon a number of different factors, such as desired expression levels, polypeptide modifications that are desirable or necessary for activity
10 (such as glycosylation or phosphorylation) and ease of folding into a biologically-active molecule.

Mammalian cell lines available as hosts for expression are well known in the art and include, but are not limited to, many immortalized cell lines available from the American Type Culture Collection (ATCC), such as Chinese hamster ovary (CHO) cells,
15 HeLa cells, baby hamster kidney (BHK) cells, monkey kidney cells (COS), human hepatocellular carcinoma cells (*e.g.*, Hep G2), and a number of other cell lines. In certain embodiments, cell lines may be selected through determining which cell lines have high expression levels of FoxM1B protein.

Selection of an appropriate target cell will also depend on the various factors
20 discussed above for selection of an appropriate host cell. In addition, a target cell can be selected based on the disease or condition that affects a patient who is to be treated by methods of the invention. For example, if a patient has a lung injury, a lung cell can be chosen as the appropriate target cell. A target cell can be, for example, a cell from or in

the patient himself or a cell from a genetically suitable donor. A “genetically suitable donor” is a donor whose tissues present a low likelihood of being rejected by the recipient once introduced or transplanted.

Alternatively, expression of FoxM1B polypeptide in a cell can be decreased, by
5 decreasing or inhibiting expression of a gene or genes (*e.g.*, transcription factors) and/or
increasing the expression of a gene or genes (*e.g.*, transcriptional repressors) in a manner
which results in decreased FoxM1B polypeptide production from the cell’s endogenous
FoxM1B gene. This method includes introducing a non-naturally occurring polypeptide
(*e.g.*, a polypeptide comprising a site-specific DNA binding domain fused to a
10 transcriptional factor domain) into the cell such that decreased FoxM1B polypeptide
production from the cell’s endogenous FoxM1B gene results.

The present invention further relates to DNA constructs useful in the method of
altering expression of a target gene. In certain embodiments, the exemplary DNA
constructs comprise: (a) one or more targeting sequences, (b) a regulatory sequence, (c)
15 an exon, and (d) an unpaired splice-donor site. The targeting sequence in the DNA
construct directs the integration of elements (a) - (d) into a target gene in a cell such that
the elements (b) - (d) are operatively linked to sequences of the endogenous target gene.
In another embodiment, the DNA constructs comprise: (a) one or more targeting
sequences, (b) a regulatory sequence, (c) an exon, (d) a splice-donor site, (e) an intron,
20 and (f) a splice-acceptor site, wherein the targeting sequence directs the integration of
elements (a) - (f) such that the elements of (b) - (f) are operatively linked to the
endogenous gene. The targeting sequence is homologous to the preselected site in the
cellular chromosomal DNA with which homologous recombination is to occur. In the

construct, the exon is generally 3' of the regulatory sequence and the splice-donor site is 3' of the exon.

If the sequence of a particular gene is known, such as the nucleic acid sequence of FoxM1B polypeptide presented herein, a DNA fragment that is complementary to a
5 selected region of the gene can be synthesized or otherwise obtained, such as by appropriate restriction of the native DNA at specific recognition sites bounding the region of interest. This fragment serves as a targeting sequence upon insertion into the cell and will hybridize to its homologous region within the genome. If this hybridization occurs during DNA replication, this DNA fragment, and any additional sequence attached
10 thereto, will be incorporated into the newly synthesized daughter strand of DNA. The present invention, therefore, includes nucleotides encoding a FoxM1B polypeptide, which nucleotides may be used as targeting sequences.

As demonstrated herein, FoxM1B-dependent transcription requires binding of the Cdk1-Cyclin B complex through an LXLXXL (SEQ ID NO: 3) motif in the FoxM1B
15 transcriptional activation domain. The data provided in the Examples below show that FoxM1B protein recruits Cdk1-Cyclin B or Cdk2-Cyclin E to efficiently phosphorylate the FoxM1B protein at Thr residue 596. Adjacent to the LXLXXL (SEQ ID NO: 3) motif is a Cdk phosphorylation site at Thr 596, whose retention is essential for FoxM1B-dependent transcription by mediating recruitment of p300/CBP coactivator
20 proteins, which provides accessibility of the local chromatin structure through acetylation of histone proteins. Consistent with these findings, stimulation of Cdk1 activity together with increased CBP coactivator levels provided a 6.2-fold increase in FoxM1B-dependent transcription, whereas inhibiting Cdk1 function significantly diminished

FoxM1B transcriptional activity. The results described herein suggest a positive feedback loop in which Cdk1 phosphorylation stimulates FoxM1B-mediated Cdc25B transcription and Cdc25B phosphatase further potentiates Cdk1 activity. Also, the Examples below demonstrate that inhibition of the Ras/MAPK and PI3K/PDK1 pathways
5 separately or together results in significant decreases in FoxM1B-dependent transcriptional activity, indicating that these cascades are essential for FoxM1B transcriptional activity.

In one embodiment, the invention provides methods for inhibiting proliferation of a tumor cell comprising the step of inhibiting FoxM1B activity in the tumor cell. Several
10 methods of inhibiting FoxM1B activity can be used to accomplish the methods of the invention. For example, FoxM1B activity in a cell can be inhibited by causing FoxM1B protein to localize in the cytoplasm, rather than in the nucleus. Causing FoxM1B to localize in the cytoplasm can be accomplished, for example, by contacting a cell with a compound that causes FoxM1B to translocate from the nucleus to the cytoplasm, or that
15 sequesters FoxM1B in the cytoplasm and prevents FoxM1B from translocating from the cytoplasm to the nucleus. Such compounds can be identified using screening methods of the invention as described herein.

In addition, FoxM1B localization can be controlled by interfering with the ability of FoxM1B to interact with cellular proteins that may be necessary for nuclear
20 localization of FoxM1B. FoxM1B localization can also be altered by interfering with compounds or proteins that are induce nuclear localization of FoxM1B. For example, growth hormone can cause expression and nuclear localization of FoxM1B in a cell (see, *for example*, co-owned and co-pending U.S. patent application, Serial Number

10/151,587, filed May 17, 2002 and explicitly incorporated by reference herein). Thus, in a tumor cell where growth hormone is causing FoxM1B expression and nuclear localization, tumor cell proliferation could be inhibited by contacting the cell with a growth hormone inhibitor.

5 In another embodiment, an inhibitor of FoxM1B activity used in the methods of the invention can decrease FoxM1B activity by interfering with cellular proteins necessary for FoxM1B activity. For example, an inhibitor can interfere with FoxM1B binding to Cdk1 or p300/CBP or can disrupt protein activity or interactions in the Ras/MAPK or PI3K/PDK1 pathways. In another embodiment, FoxM1B activity can be
10 inhibited by contacting a tumor cell with a tyrphostin, for example, a Jak2 kinase inhibitor, such as AG490, which interferes with the pathway through which growth hormone activates FoxM1B.

In another aspect, FoxM1B activity can be inhibited by contacting a tumor cell with an antisense construct, wherein the antisense oligonucleotide is complementary to
15 nucleic acid sequences of RNA or double-stranded DNA that encodes FoxM1B and that inhibits FoxM1B gene expression. Antisense oligonucleotides of the invention can be complementary to and hybridize with expression control sequences (such as triple helix formation) or to FoxM1B mRNA. For example, antisense DNA or RNA molecules, which have a sequence that is complementary to at least a portion of a FoxM1B gene can
20 be introduced into a cell to interfere with expression of FoxM1B gene. Antisense oligonucleotides can be designed by available techniques using the sequence of the FoxM1B gene disclosed herein. Typically, an antisense molecule will be complementary to the start site (5' end) of the FoxM1B gene. When the antisense molecule then

hybridizes to the corresponding FoxM1B mRNA, translation of this mRNA is prevented or reduced.

Alternatively, gene therapy can be employed to create a dominant-negative inhibitor of FoxM1B. In these embodiments, DNA encoding a mutant polypeptide of FoxM1B or FoxM1B activity inhibiting peptide fragment thereof can be prepared and introduced into the cells of a patient using either viral or non-viral methods as described herein. Each such mutant is typically designed to compete with endogenous FoxM1B in its biological role.

In one embodiment of the invention, an effective inhibitor of FoxM1B activity causes at least about 50% reduction in FoxM1B activity. Preferably, an effective inhibitor of FoxM1B activity causes at least about 80% reduction in FoxM1B activity. Most preferably, an inhibitor of FoxM1B activity causes at least about 90% reduction in FoxM1B activity.

In another embodiment, the invention provides screening methods for identifying compounds that can prevent tumor progression and inhibit tumor cell proliferation. The screening methods of the invention comprise identifying compounds that can inhibit FoxM1B activity or FoxM1B nuclear localization. For example, one embodiment of the screening methods of the invention comprises the steps of: contacting with a candidate compound a plurality of cells comprising a FoxM1B gene, wherein the cells express FoxM1B protein when cultured *in vitro*; assaying FoxM1B localization in the cells; and identifying a candidate compound when FoxM1B is localized in the cytoplasm and not in the nuclei of cells contacted with the compound but localized in the nuclei of cells not contacted with the compound.

Another embodiment of the screening methods of the invention comprises the steps of: contacting with a candidate compound a plurality of cells comprising a FoxM1B gene, wherein the cells express FoxM1B protein when cultured *in vitro*; assaying FoxM1B localization in the cells; selecting a candidate compound when FoxM1B is
5 localized in the cytoplasm and not in the nuclei of cells contacted with the compound but localized in the nuclei of cells not contacted with the compound; and identifying a compound as a compound that can inhibit tumor progression if proliferation of tumor cells is inhibited when contacted with the compound *in vitro* or *in vivo*.

In yet another embodiment, the screening methods of the invention can comprise
10 a pre-selection step, wherein a compound can be pre-selected for a screening method of the invention by contacting a plurality of cells with a candidate compound and assaying for cell proliferation, wherein a candidate compound is selected for a screening method of the invention if cell proliferation is inhibited (*i.e.* the cells proliferate more slowly or not at all in the presence than in the absence of the compound).

15 Still other embodiments of the screening methods of the invention comprise the steps of: contacting a cell with a compound, wherein the cell expresses a green fluorescent protein-FoxM1B (GFP-FoxM1B) fusion protein; contacting the cell with growth hormone; detecting localization of the GFP-FoxM1B protein in the cells; and identifying a compound as a compound that inhibits FoxM1B localization if the GFP
20 FoxM1B protein is localized in the cytoplasm and not the nuclei of the cells.

Yet another embodiment of the screening methods of the invention comprises the steps of: contacting a transgenic mouse with a compound, wherein the cells of the transgenic mouse express a green fluorescent protein-FoxM1B (GFP-FoxM1B) fusion

protein; administering growth hormone to the mouse; detecting localization of the GFP-FoxM1B protein in a cell removed from the mouse; and identifying a compound as a compound that inhibits FoxM1B nuclear localization if the GFP-FoxM1B protein is localized in the cytoplasm but not the nucleus of the cell that is removed from the mouse.

5 Assaying for nuclear localization and expression of FoxM1B protein can be accomplished by any method known the art. For example, immunohistochemistry using detectably-labeled primary anti-FoxM1B antibodies, or unlabeled primary anti-FoxM1B and detectably-labeled secondary antibodies (*for example*, labeled with fluorescent markers, such as fluorescein isothiocyanate, FITC), can be used to visualize FoxM1B
10 protein localization, *inter alia*, by fluorescence microscopy. Alternative labels, such as radioactive, enzymatic and hapten labels, are within the scope of this invention.

 As used herein, the terms “label” or “labeled” refers to incorporation of a detectable marker, *e.g.*, by incorporation of a radiolabeled amino acid or attachment to a polypeptide of biotin moieties that can be detected by marked avidin (*e.g.*, streptavidin
15 containing a fluorescent marker or enzymatic activity that can be detected by optical or colorimetric methods). In certain embodiments, the label or marker can also be therapeutic. Various methods of labeling polypeptides and glycoproteins can be used that are known in the art. Examples of labels for polypeptides include, but are not limited to, the following: radioisotopes or radionuclides (*e.g.*, ^3H , ^{14}C , ^{15}N , ^{35}S , ^{90}Y , ^{99}Tc , ^{111}In , ^{125}I ,
20 ^{131}I), fluorescent labels (*e.g.*, FITC, rhodamine, lanthanide phosphors), enzymatic labels (*e.g.*, horseradish peroxidase, β -galactosidase, luciferase, alkaline phosphatase), chemiluminescent groups, biotin, and predetermined polypeptide epitopes recognized by a secondary reporter (*e.g.*, leucine zipper pair sequences, binding sites for secondary

antibodies, metal binding domains, epitope tags). In certain embodiments, labels are attached by spacer arms of various lengths (such as $-(CH_2)_n-$, $n = 1-50$, more preferably 1-20) to reduce steric hindrance.

Compounds identified in these screens can be used in the methods of inhibiting
5 tumor cell proliferation, as discussed herein below.

The screening methods of the invention can also be used to identify endogenous FoxM1B inhibitor polypeptides by contacting cells with known polypeptides instead of test compounds. Such polypeptides can be used to inhibit FoxM1B activity as described herein.

10 In certain embodiments, the invention provides a method of inhibiting tumor growth in an animal comprising administering to the animal, which has at least one tumor cell present in its body, a therapeutically effective amount of an antisense oligonucleotide, for a therapeutically effective period of time, wherein the antisense oligonucleotide is complementary to nucleic acid sequences of RNA or double-stranded
15 DNA that encodes FoxM1B and which inhibits FoxM1B gene expression. In another embodiment, the invention provides a method of inhibiting tumor growth in an animal comprising inhibiting FoxM1B activity in a tumor cell in the animal, for example, by administering to the animal, which has at least one tumor cell present in its body, a therapeutically effective amount of a compound that inhibits FoxM1B activity. Such
20 compounds can be identified using screening methods of the invention as described herein.

In certain embodiments, the invention provides pharmaceutical compositions comprising a therapeutically effective amount of a compound that inhibits FoxM1B

expression, nuclear localization or expression and or nuclear localization in mammalian cells together with a pharmaceutically acceptable diluent, carrier, solubilizer, emulsifier, preservative and/or adjuvant. In other embodiments, the invention provides pharmaceutical compositions that comprise a therapeutically effective amount of a compound that inhibits FoxM1B expression in mammalian cells and also induces FoxM1B protein to translocate into the cytoplasm from the nucleus of tumor cells together with a pharmaceutically acceptable diluent, carrier, solubilizer, emulsifier, preservative and/or adjuvant. Such compounds can be identified in screening methods of the invention. The invention further provides pharmaceutical compositions comprising a peptide having an amino acid sequence as set forth in SEQ ID NO: 10, SEQ ID NO: 11, or SEQ ID NO: 12.

The term “agent” is used herein to denote a chemical compound, a mixture of chemical compounds, a biological macromolecule, or an extract made from biological materials.

The term “pharmaceutical composition” as used herein refers to a composition comprising a pharmaceutically acceptable carrier, excipient, or diluent and a chemical compound, peptide, or composition as described herein that is capable of inducing a desired therapeutic effect when properly administered to a patient.

The term “therapeutically effective amount” refers to the amount of growth hormone or a pharmaceutical composition of the invention or a compound identified in a screening method of the invention determined to produce a therapeutic response in a mammal. Such therapeutically effective amounts are readily ascertained by one of ordinary skill in the art and using methods as described herein.

As used herein, “substantially pure” means an object species that is the predominant species present (*i.e.*, on a molar basis it is more abundant than any other individual species in the composition). In certain embodiments, a substantially purified fraction is a composition wherein the object species comprises at least about 50 percent
5 (on a molar basis or on a weight or number basis) of all macromolecular species present. In certain embodiments, a substantially pure composition will comprise more than about 80%, 85%, 90%, 95%, or 99% of all macromolecular species present in the composition. In certain embodiments, the object species is purified to essential homogeneity (wherein contaminating species cannot be detected in the composition by conventional detection
10 methods) wherein the composition consists essentially of a single macromolecular species.

The term “patient” includes human and animal subjects.

As used herein, the terms “tumor growth” and “tumor cell proliferation” are used to refer to the growth of a tumor cell. The term “tumor cell” as used herein refers to a
15 cell that is neoplastic. A tumor cell can be benign, *i.e.* one that does not form metastases and does not invade and destroy adjacent normal tissue, or malignant, *i.e.* one that invades surrounding tissues, is capable of producing metastases, may recur after attempted removal, and is likely to cause death of the host. Preferably a tumor cell that is subjected to a method of the invention is an epithelial-derived tumor cell, such as a tumor
20 cell derived from skin cells, lung cells, intestinal epithelial cells, colon epithelial cells, testes cells, breast cells, prostate cells, brain cells, bone marrow cells, blood lymphocytes, ovary cells or thymus cells.

Acceptable formulation materials preferably are nontoxic to recipients at the dosages and concentrations employed. The pharmaceutical composition may contain formulation materials for modifying, maintaining or preserving, for example, the pH, osmolarity, viscosity, clarity, color, isotonicity, odor, sterility, stability, rate of dissolution or release, adsorption or penetration of the composition. Suitable formulation materials include, but are not limited to, amino acids (such as glycine, glutamine, asparagine, arginine or lysine); antimicrobials; antioxidants (such as ascorbic acid, sodium sulfite or sodium hydrogen-sulfite); buffers (such as borate, bicarbonate, Tris-HCl, citrates, phosphates or other organic acids); bulking agents (such as mannitol or glycine); chelating agents (such as ethylenediamine tetraacetic acid (EDTA)); complexing agents (such as caffeine, polyvinylpyrrolidone, beta-cyclodextrin or hydroxypropyl-beta-cyclodextrin); fillers; monosaccharides, disaccharides, and other carbohydrates (such as glucose, mannose or dextrans); proteins (such as serum albumin, gelatin or immunoglobulins); coloring, flavoring and diluting agents; emulsifying agents; hydrophilic polymers (such as polyvinylpyrrolidone); low molecular weight polypeptides; salt-forming counterions (such as sodium); preservatives (such as benzalkonium chloride, benzoic acid, salicylic acid, thimerosal, phenethyl alcohol, methylparaben, propylparaben, chlorhexidine, sorbic acid or hydrogen peroxide); solvents (such as glycerin, propylene glycol or polyethylene glycol); sugar alcohols (such as mannitol or sorbitol); suspending agents; surfactants or wetting agents (such as pluronics, PEG, sorbitan esters, polysorbates such as polysorbate 20 and polysorbate 80, Triton, trimethamine, lecithin, cholesterol, or tyloxapal); stability enhancing agents (such as sucrose or sorbitol); tonicity enhancing agents (such as alkali metal halides, preferably

sodium or potassium chloride, mannitol, or sorbitol); delivery vehicles; diluents; excipients and/or pharmaceutical adjuvants. *See, for example*, REMINGTON'S PHARMACEUTICAL SCIENCES, 18th Edition, (A.R. Gennaro, ed.), 1990, Mack Publishing Company.

5 Optimal pharmaceutical compositions can be determined by one skilled in the art depending upon, for example, the intended route of administration, delivery format and desired dosage. *See, for example*, REMINGTON'S PHARMACEUTICAL SCIENCES, *Id.* Such compositions may influence the physical state, stability, rate of *in vivo* release and rate of *in vivo* clearance of the antibodies of the invention.

10 The primary vehicle or carrier in a pharmaceutical composition may be either aqueous or non-aqueous in nature. For example, a suitable vehicle or carrier may be water for injection, physiological saline solution or artificial cerebrospinal fluid, possibly supplemented with other materials common in compositions for parenteral administration. Neutral buffered saline or saline mixed with serum albumin are further
15 exemplary vehicles. Pharmaceutical compositions can comprise Tris buffer of about pH 7.0-8.5, or acetate buffer of about pH 4.0-5.5, which may further include sorbitol or a suitable substitute therefor. Pharmaceutical compositions of the invention may be prepared for storage by mixing the selected composition having the desired degree of
20 purity with optional formulation agents (REMINGTON'S PHARMACEUTICAL SCIENCES, *Id.*) in the form of a lyophilized cake or an aqueous solution. Further, the FoxM1B-inhibiting product may be formulated as a lyophilizate using appropriate excipients such as sucrose.

Formulation components are present in concentrations that are acceptable to the site of administration. Buffers are advantageously used to maintain the composition at

physiological pH or at a slightly lower pH, typically within a pH range of from about 5 to about 8.

The pharmaceutical compositions of the invention can be delivered parenterally.

When parenteral administration is contemplated, the therapeutic compositions for use in
5 this invention may be in the form of a pyrogen-free, parenterally acceptable aqueous
solution comprising the desired compound identified in a screening method of the
invention in a pharmaceutically acceptable vehicle. A particularly suitable vehicle for
parenteral injection is sterile distilled water in which the compound identified in a
screening method of the invention is formulated as a sterile, isotonic solution,
10 appropriately preserved. Preparation can involve the formulation of the desired molecule
with an agent, such as injectable microspheres, bio-erodible particles, polymeric
compounds (such as polylactic acid or polyglycolic acid), beads or liposomes, that may
provide controlled or sustained release of the product which may then be delivered via a
depot injection. Formulation with hyaluronic acid has the effect of promoting sustained
15 duration in the circulation. Implantable drug delivery devices may be used to introduce
the desired molecule.

The compositions may be formulated for inhalation. In these embodiments, a
compound identified in a screening method of the invention or a FoxM1B inhibitor
disclosed herein is formulated as a dry powder for inhalation, or inhalation solutions may
20 also be formulated with a propellant for aerosol delivery, such as by nebulization.
Pulmonary administration is further described in PCT Application No.
PCT/US94/001875, which describes pulmonary delivery of chemically modified proteins
and is incorporated by reference.

The pharmaceutical compositions of the invention can be delivered through the digestive tract, such as orally. The preparation of such pharmaceutically acceptable compositions is within the skill of the art. A FoxM1B inhibitor disclosed herein or compounds of the invention that are administered in this fashion may be formulated with
5 or without those carriers customarily used in the compounding of solid dosage forms such as tablets and capsules. A capsule may be designed to release the active portion of the formulation at the point in the gastrointestinal tract when bioavailability is maximized and pre-systemic degradation is minimized. Additional agents can be included to facilitate absorption of the FoxM1B inhibitor disclosed herein or compound identified in
10 a screening method of the invention. Diluents, flavorings, low melting point waxes, vegetable oils, lubricants, suspending agents, tablet disintegrating agents, and binders may also be employed.

A pharmaceutical composition may involve an effective quantity of a FoxM1B inhibitor disclosed herein or a compound identified in a screening method of the
15 invention in a mixture with non-toxic excipients that are suitable for the manufacture of tablets. By dissolving the tablets in sterile water, or another appropriate vehicle, solutions may be prepared in unit-dose form. Suitable excipients include, but are not limited to, inert diluents, such as calcium carbonate, sodium carbonate or bicarbonate, lactose, or calcium phosphate; or binding agents, such as starch, gelatin, or acacia; or
20 lubricating agents such as magnesium stearate, stearic acid, or talc.

Additional pharmaceutical compositions are evident to those skilled in the art, including formulations involving a FoxM1B inhibitor disclosed herein or compounds of the invention in sustained- or controlled-delivery formulations. Techniques for

formulating a variety of other sustained- or controlled-delivery means, such as liposome carriers, bio-erodible microparticles or porous beads and depot injections, are also known to those skilled in the art. *See, for example*, PCT Application No. PCT/US93/00829, which describes the controlled release of porous polymeric microparticles for the delivery
5 of pharmaceutical compositions. Sustained-release preparations may include semipermeable polymer matrices in the form of shaped articles, *e.g.* films, or microcapsules, polyesters, hydrogels, polylactides (U.S. 3,773,919 and EP 058,481), copolymers of L-glutamic acid and gamma ethyl-L-glutamate (Sidman *et al.*, 1983, *Biopolymers* 22: 547-556), poly (2-hydroxyethyl-methacrylate) (Langer *et al.*, 1981, *J.*
10 *Biomed. Mater. Res.* 15: 167-277) and Langer, 1982, *Chem. Tech.* 12: 98-105), ethylene vinyl acetate (Langer *et al.*, *id.*) or poly-D(-)-3-hydroxybutyric acid (EP 133,988). Sustained release compositions may also include liposomes, which can be prepared by any of several methods known in the art. *See e.g.*, Eppstein *et al.*, 1985, *Proc. Natl. Acad. Sci. USA* 82: 3688-3692; EP 036,676; EP 088,046 and EP 143,949.

15 The pharmaceutical composition to be used for *in vivo* administration typically is sterile. In certain embodiments, this may be accomplished by filtration through sterile filtration membranes. In certain embodiments, where the composition is lyophilized, sterilization using this method may be conducted either prior to or following lyophilization and reconstitution. In certain embodiments, the composition for parenteral
20 administration may be stored in lyophilized form or in a solution. In certain embodiments, parenteral compositions generally are placed into a container having a sterile access port, for example, an intravenous solution bag or vial having a stopper pierceable by a hypodermic injection needle.

Once the pharmaceutical composition of the invention has been formulated, it may be stored in sterile vials as a solution, suspension, gel, emulsion, solid, or as a dehydrated or lyophilized powder. Such formulations may be stored either in a ready-to-use form or in a form (*e.g.*, lyophilized) that is reconstituted prior to administration.

5 The present invention is directed to kits for producing a single-dose administration unit. Kits according to the invention may each contain both a first container having a dried protein compound identified in a screening method of the invention and a second container having an aqueous formulation, including for example single and multi-chambered pre-filled syringes (*e.g.*, liquid syringes, lyosyringes or
10 needle-free syringes).

 The effective amount of a pharmaceutical composition of the invention to be employed therapeutically will depend, for example, upon the therapeutic context and objectives. One skilled in the art will appreciate that the appropriate dosage levels for treatment, according to certain embodiments, will thus vary depending, in part, upon the
15 molecule delivered, the indication for which the pharmaceutical composition is being used, the route of administration, and the size (body weight, body surface or organ size) and/or condition (the age and general health) of the patient. A clinician may titer the dosage and modify the route of administration to obtain the optimal therapeutic effect. Typical dosages range from about 0.1 µg/kg to up to about 100 mg/kg or more,
20 depending on the factors mentioned above. In certain embodiments, the dosage may range from 0.1 µg/kg up to about 100 mg/kg; or 1 µg/kg up to about 100 mg/kg; or 5 µg/kg up to about 100 mg/kg.

The dosing frequency will depend upon the pharmacokinetic parameters of a FoxM1B inhibitor disclosed herein or compound identified in a screening method of the invention in the formulation. For example, a clinician administers the composition until a dosage is reached that achieves the desired effect. The composition may therefore be administered as a single dose, or as two or more doses (which may or may not contain the same amount of the desired molecule) over time, or as a continuous infusion via an implantation device or catheter. Further refinement of the appropriate dosage is routinely made by those of ordinary skill in the art and is within the ambit of tasks routinely performed by them. Appropriate dosages may be ascertained through use of appropriate dose-response data.

Administration routes for the pharmaceutical compositions of the invention include orally, through injection by intravenous, intraperitoneal, intracerebral (intraparenchymal), intracerebroventricular, intramuscular, intra-ocular, intraarterial, intraportal, or intralesional routes; by sustained release systems or by implantation devices. The pharmaceutical compositions may be administered by bolus injection or continuously by infusion, or by implantation device. The pharmaceutical composition also can be administered locally *via* implantation of a membrane, sponge or another appropriate material onto which the desired molecule has been absorbed or encapsulated. Where an implantation device is used, the device may be implanted into any suitable tissue or organ, and delivery of the desired molecule may be via diffusion, timed-release bolus, or continuous administration.

In certain embodiments, it may be desirable to use a FoxM1B inhibitor disclosed herein or pharmaceutical compositions of compounds identified in a screening method of

the invention in an *ex vivo* manner. In such instances, cells, tissues or organs that have been removed from the patient are exposed to pharmaceutical compositions of the invention or a recombinant nucleic acid construct encoding a FoxM1B inhibitor disclosed herein after which the cells, tissues and/or organs are subsequently implanted back into
5 the patient.

In certain embodiments, a FoxM1B inhibitor disclosed herein, a FoxM1B inhibitor encoding recombinant nucleic acid constructs or pharmaceutical compositions of compounds identified in a screening method of the invention can be delivered by implanting certain cells that have been genetically engineered, using methods such as
10 those described herein, to express and secrete the polypeptide. Such cells may be animal or human cells, and may be autologous, heterologous, or xenogeneic, or may be immortalized. In order to decrease the chances of an immunological response, the cells may be encapsulated to avoid infiltration of surrounding tissues. Encapsulation materials are typically biocompatible, semi-permeable polymeric enclosures or membranes that
15 allow the release of the protein product(s) but prevent the destruction of the cells by the patient's immune system or by other detrimental factors from the surrounding tissues.

Pharmaceutical compositions of the invention can be administered alone or in combination with other therapeutic agents, in particular, in combination with other cancer therapy agents. Such agents generally include radiation therapy or chemotherapy.
20 Chemotherapy, for example, can involve treatment with one or more of the following agents: anthracyclines, taxol, tamoxifene, doxorubicin, 5-fluorouracil, and other drugs known to one skilled in the art.

Anit-FoxM1B polypeptide cell therapy, *e.g.*, the implantation of cells producing polypeptides that inhibit FoxM1B activity, is also provided herein. This embodiment of the invention involves implanting cells capable of synthesizing and secreting a biologically active form of a polypeptide of a FoxM1B inhibitor. Such FoxM1B inhibitor polypeptide-producing cells can be cells that are natural producers of FoxM1B inhibitor polypeptides or may be recombinant cells whose ability to produce FoxM1B inhibitor polypeptides has been augmented by transformation with a gene encoding the desired polypeptide or with a gene augmenting the expression of the polypeptide. Such a modification may be accomplished by means of a vector suitable for delivering the gene as well as promoting its expression and secretion. In order to minimize potential immunological reaction in patients being administered an inhibitor polypeptide, as may occur with the administration of a polypeptide of a foreign species, it is preferred that natural cells producing FoxM1B inhibitor polypeptide be of human origin, most preferably autologous to the individual in whom they are implanted, and produce human FoxM1B inhibitor polypeptide. Likewise, it is preferred that the recombinant cells, most preferably cells autologous to the individual in whom they are implanted, that produce FoxM1B inhibitor polypeptide be transformed with an expression vector containing a gene encoding a human FoxM1B inhibitor polypeptide.

Implanted cells may be encapsulated to avoid infiltration of surrounding tissue. Human or non-human animal cells may be implanted in patients in biocompatible, semipermeable polymeric enclosures or membranes that permit release of FoxM1B inhibitor polypeptide, but that prevent destruction of the cells by the patient's immune system or by other detrimental factors from surrounding tissue. Alternatively, autologous

cells, *i.e.*, the patient's own cells, transformed to produce FoxM1B inhibitor polypeptides *ex vivo*, may be implanted directly into the patient without such encapsulation.

Techniques for the encapsulation of living cells are known in the art, and preparation of encapsulated cells and their implantation in patients may be routinely accomplished. For example, Baetge *et al.* (PCT Pub. No. WO 95/05452 and PCT/US94/09299) describe membrane capsules containing genetically engineered cells for effective delivery of biologically active molecules. The capsules are biocompatible and are easily retrievable. The capsules encapsulate cells transfected with recombinant DNA molecules comprising DNA sequences encoding biologically active molecules operatively linked to promoters that are not subject to down-regulation *in vivo* upon implantation into a mammalian host. Such devices provide for the delivery of the molecules from living cells to specific sites within a recipient. *See* U.S. Patent Nos. 4,892,538; 5,011,472; and 5,106,627. A system for encapsulating living cells is described in PCT Pub. No. WO 91/10425 (Aebischer *et al.*). *See also*, PCT Pub. No. WO 91/10470 (Aebischer *et al.*); Winn *et al.*, 1991, *Exper. Neurol.* 113:322-29; Aebischer *et al.*, 1991, *Exper. Neurol.* 111:269-75; and Tresco *et al.*, 1992, *ASAIO* 38:17-23 for art-recognized systems for encapsulating living cells.

In vivo, *ex vivo* and *in vitro* gene delivery of FoxM1B inhibitor polypeptides or antisense oligonucleotides is also provided herein. One example of a gene therapy technique is to use an antisense oligonucleotide of the FoxM1B gene (either genomic DNA, cDNA, and/or mRNA) that is complementary to a portion of the gene encoding a FoxM1B polypeptide that can be operatively linked to a constitutive or inducible promoter to form a "gene therapy DNA construct." The promoter may be homologous or

heterologous to the endogenous FoxM1B gene, provided that it is active in the cell or tissue type into which the construct is inserted. Other components of the gene therapy DNA construct may optionally include DNA molecules designed for site-specific integration (*e.g.*, endogenous sequences useful for homologous recombination), tissue-specific promoters, enhancers or silencers, DNA molecules capable of providing a selective advantage over the parent cell, DNA molecules useful as labels to identify transformed cells, negative selection systems, cell specific binding agents (for example, for cell targeting), cell-specific internalization factors, transcription factors enhancing expression from a vector, and factors enabling vector production.

A gene therapy DNA construct can then be introduced into cells (either *ex vivo* or *in vivo*) using viral or non-viral vectors. One means for introducing the gene therapy DNA construct is by means of viral vectors as described herein. Certain vectors, such as retroviral vectors, will deliver the DNA construct to the chromosomal DNA of the cells, and the gene can integrate into the chromosomal DNA. Other vectors will function as episomes, and the gene therapy DNA construct will remain unintegrated, *for example*, in the cell cytoplasm. Other suitable methods for delivering nucleic acid constructs into cells are disclosed in US Patent Number 6,475,798 filed November 5, 2002; US Patent Number 6,291,243 filed September 18, 2001; and US Patent Application Number 20030033615 filed February 13, 2003, all of which are hereby incorporated by reference.

In yet other embodiments, regulatory elements can be included for controlled expression of the antisense oligonucleotide or a FoxM1B inhibitor polypeptide in the target cell. Such elements are activated in response to an appropriate effector. In this way, a therapeutic polypeptide can be expressed when desired. One conventional control

means involves the use of small molecule dimerizers or rapalogs to dimerize chimeric proteins which contain a small molecule-binding domain and a domain capable of initiating a biological process, such as a DNA-binding protein or transcriptional activation protein (*see* PCT Pub. Nos. WO 96/41865, WO 97/31898, and WO 97/31899).

5 The dimerization of the proteins can be used to initiate transcription of the transgene.

In vivo gene therapy may be accomplished by introducing the gene encoding FoxM1B inhibitor polypeptide or an antisense oligonucleotide into cells *via* local delivery of a FoxM1B nucleic acid molecule, by direct injection or by other appropriate viral or non-viral delivery vectors. (Hefti, 1994, *Neurobiology* 25:1418-35.) For example, a
10 nucleic acid molecule encoding a FoxM1B polypeptide may be contained in an adeno-associated virus (AAV) vector for delivery to the targeted cells (*see, e.g.*, Johnson, PCT Pub. No. WO 95/34670; PCT App. No. PCT/US95/07178). The recombinant AAV genome used according to the teachings of the invention typically contains AAV inverted terminal repeats flanking a DNA sequence encoding a FoxM1B polypeptide operatively
15 linked to functional promoter and polyadenylation sequences.

Alternative suitable viral vectors include, but are not limited to, retrovirus, adenovirus, herpes simplex virus, lentivirus, hepatitis virus, parvovirus, papovavirus, poxvirus, alphavirus, coronavirus, rhabdovirus, paramyxovirus, and papilloma virus vectors. U.S. Patent No. 5,672,344 describes an *in vivo* viral-mediated gene transfer
20 system involving a recombinant neurotrophic HSV-1 vector. U.S. Patent No. 5,399,346 provides examples of a process for providing a patient with a therapeutic protein by the delivery of human cells that have been treated *in vitro* to insert a DNA segment encoding a therapeutic protein. Additional methods and materials for the practice of gene therapy

techniques are described in U.S. Patent Nos. 5,631,236 (involving adenoviral vectors), 5,672,510 (involving retroviral vectors), and 5,635,399 (involving retroviral vectors expressing cytokines).

Nonviral delivery methods include, but are not limited to, liposome-mediated
5 transfer, naked DNA delivery (*e.g.*, by direct injection), receptor-mediated transfer (ligand-DNA complex), electroporation, calcium phosphate precipitation, and microparticle bombardment (*e.g.*, gene gun). Gene therapy materials and methods may also include inducible promoters, tissue-specific enhancer-promoters, DNA sequences designed for site-specific integration, DNA sequences capable of providing a selective
10 advantage over the parent cell, labels to identify transformed cells, negative selection systems and expression control systems (safety measures), cell-specific binding agents (for cell targeting), cell-specific internalization factors, and transcription factors to enhance expression by a vector as well as methods of vector manufacture. Such additional methods and materials for the practice of gene therapy techniques are
15 described in U.S. Patent Nos. 4,970,154 (involving electroporation techniques), 5,679,559 (describing a lipoprotein-containing system for gene delivery), 5,676,954 (involving liposome carriers), 5,593,875 (describing methods for calcium phosphate transfection), and 4,945,050 (describing a process wherein biologically active particles are propelled at cells at a speed whereby the particles penetrate the surface of the cells
20 and become incorporated into the interior of the cells), and PCT Pub. No. WO 96/40958 (involving nuclear ligands).

It is also contemplated that FoxM1B gene therapy or cell therapy can further include the delivery of one or more additional polypeptide(s) in the same or a different

cell(s). Such cells may be separately introduced into the patient, or the cells may be contained in a single implantable device, such as the encapsulating membrane described above, or the cells may be separately modified by means of viral vectors.

Another means of increasing endogenous FoxM1B inhibitor polypeptide
5 expression in a cell *via* gene therapy is to insert one or more enhancer elements into the FoxM1B inhibitor polypeptide promoter, where the enhancer elements can serve to increase transcriptional activity of the FoxM1B inhibitor gene. The enhancer elements used are selected based on the tissue in which one desires to activate the gene – enhancer elements known to confer promoter activation in that tissue are preferred. For example,
10 if a gene encoding a FoxM1B inhibitor polypeptide is to be “turned on” in T-cells, the *lck* promoter enhancer element may be used. Here, the functional portion of the transcriptional element to be added may be inserted into a fragment of DNA containing the FoxM1B inhibitor polypeptide promoter (and optionally, inserted into a vector and/or 5’ and/or 3’ flanking sequences) using standard cloning techniques. This construct,
15 known as a “homologous recombination construct,” can then be introduced into the desired cells either *ex vivo* or *in vivo*.

The following Examples are provided for the purposes of illustration and are not intended to limit the scope of the present invention. The present invention is not to be limited in scope by the exemplified embodiments, which are intended as illustrations of
20 individual aspects of the invention. Indeed, various modifications of the invention in addition to those shown and described herein will become apparent to those skilled in the art from the foregoing description and accompanying drawings. Such modifications are intended to fall within the scope of the appended claims.

EXAMPLES

Example 1

Generation of Conditional FoxM1B Knockout Mice

5 FoxM1B knockout mice die immediately after birth. Therefore, to examine the role of FoxM1B in adult tissues, conditional FoxM1B knockout mice were generated using a triple-LoxP FoxM1B targeting vector to create a “Floxed” FoxM1B targeted locus (see Figure 2 for a schematic diagram of the vector). *Cre* recombinase-mediated deletion of the FoxM1 genomic sequences spanning the two LoxP sites removes the
10 entire winged helix DNA binding domain and the C-terminal transcriptional activation domain, thereby preventing expression of functional FoxM1 isoforms. Following standard electroporation and culture of mouse embryonic stem (ES) cells to select for homologous recombination (G418 and gangcyclovir), homologous recombinants were identified by Southern blotting of ES cell genomic DNA.

15 Mouse blastocysts were injected with the ES cells comprising the “Floxed” (fl/+) FoxM1B targeted allele, and chimeric mice with germ line transmission were selected. Viable mice homozygous for the “Floxed” (fl/fl) FoxM1B targeted allele were generated in this manner. Mice either homozygous (fl/fl) or heterozygous (fl/+) for the FoxM1B (fl) allele were verified by PCR amplification of mouse genomic DNA with primers that
20 flanked the LoxP site. Breeding the albumin promoter *Cre* recombinase transgene into the FoxM1B (fl/fl) mouse genetic background allowed hepatocyte deletion of the FoxM1B locus within six weeks after birth, which was verified by Southern blot using liver genomic DNA.

Example 2

TTR-FoxM1B transgenic livers display increased size of hepatic preneoplastic and neoplastic nodules

5 To investigate the influence of increased FoxM1B expression on liver tumor formation, wild type (WT) and TTR-FoxM1B transgenic (TG) CD-1 mice were treated for 23 weeks with diethylnitrosamine (DEN)/Phenobarbital (PB) liver tumor induction (Goldfarb *et al.*, 1983, *Environ. Health Perspect.* 50:149-161; Russell *et al.*, 1996, *Mol. Carcinog.* 15:183-189; Slagle *et al.*, 1996, *Mol. Carcinog.* 15:261-269; Tamano *et al.*,
10 1994, *Carcinogenesis* 15:1791-1798). Transgenic CD-1 mice were generated using the – 3 kb transthyretin (TTR) promoter to constitutively express the FoxM1B transgene (SEQ ID NO: 1 as shown in Figure 1) in hepatocytes as described (Ye *et al.*, 1999, *Mol. Cell Biol.*, 19: 8570-8580). At 14 days postnatal of age 17 WT and TTR-FoxM1B TG CD-1 mice received a single IP injection of 5 µg of DEN/g body weight (10 µl/g body weight
15 of 0.05% solution of DEN in water). At 4 weeks of age, mice were placed on water containing 0.05% of PB for 21 weeks. The mice were sacrificed at 25 weeks of age, the livers were fixed in paraformaldehyde, paraffin embedded, sectioned and then H&E stained and examined for tumors. The TTR-FoxM1B TG livers exhibited larger preneoplastic and neoplastic nodules (Table 2; greater than 200 µm in size) and
20 hepatocyte proliferation was stimulated in these hepatic nodules as determined by immunohistochemical staining for Ki67 antigen. However, increased FoxM1B levels did not increase the number of hepatic tumor nodules, suggesting that FoxM1B enhanced the growth of hepatic tumors but did not stimulate tumor initiation.

Table 2

Size of liver tumor	R \geq 450 μm^a	450 μm > R \geq 200 μm^b	R < 200 μm
TTR-FoxM1B TG liver	3.6 \pm 1.3	20.3 \pm 6.1	5.7 \pm 4.0
Wild Type Liver	0.3 \pm 0.3	8.8 \pm 2.5	38.8 \pm 9.4

Table 2 shows the mean number \pm (s.e.m.) of hepatic preneoplastic or neoplastic nodules (adenomas) per cm^3 within the range of sizes shown (n= 17 for each genotype).

5 As shown in column 2 (a) and 3 (b), values are significantly different from control mice based on the Student's t-test $P=0.019$ and $P=0.0027$, respectively.

Example 3

10 **Infection of proliferating human cell lines with Adenovirus expressing antisense human FoxM1B cDNA inhibits expression of endogenous FoxM1B mRNA**

Proliferating human hepatoma HepG2 cells were infected with an increasing amounts of plaque forming units (PFU) per cell of either an adenovirus expressing antisense human FoxM1B cDNA (Figure 3A, AdFoxM1B AS) or Adenovirus expressing bacterial LacZ gene (Figure 3B, AdLacZ) and total RNA was isolated 20 hours following

15 post infection. Expression of human FoxM1B mRNA was measured using an RNase protection assay (RPA) with a FoxM1B probe as described previously (Ye *et al.*, 1999, *Mol. Cell. Biol.* 19:8570-8580; Ye *et al.*, 1997, *Mol. Cell Biol.* 17:1626-1641). These RPA studies demonstrated that AdFoxM1B AS infection at 30 pfu per cell is sufficient to inhibit endogenous FoxM1B expression (Figure 3A), but AdLacZ control infections did

20 not influence FoxM1B expression (Figure 3B). Furthermore, AdFoxM1B infection of human osteoblastoma U2OS cells was sufficient to prevent FoxM1B expression in this human tumor cell line as well (Figure 4). Taken together infection of cells with

AdFoxM1B AS is an effective means by which to inhibit FoxM1B expression in tumor cell lines.

Example 4

5 **Generation of FoxM1B expression plasmids and luciferase reporter plasmid**

The CMV-FoxM1B expression plasmid was generated by PCR amplification of the CMV Human FoxM1B expression plasmid (Ye *et al.*, 1997, *Mol. Cell Biol.* 17:1626-1641) with 5' EcoR1 T-epitope tagged FoxM1B primer:

5'-gcggaattcaccatggctagcatgactggtggacagcaaatgggtTGGCAGAACTCTGTGTCTGAG

10 (SEQ ID NO: 4) and a 3' antisense primer that hybridized to the CMV expression vector SV-40 poly A region: 5'-gtttgtccaattatgtca (SEQ ID NO: 5). The resulting 3.3 KB FoxM1B PCR product was digested with EcoR1 and HindIII, generating the 2.5 KB EcoRI-HindIII T7 tagged FoxM1B cDNA fragment and removing 800 nucleotides from the 3' untranslated region. This FoxM1B cDNA fragment was subsequently cloned in the
15 corresponding sites in the CMV expression vector (Pani *et al.*, 1992, *Mol. Cell Biol.* 12:3723-373245).

A CMV pEGFP-FoxM1B expression plasmid was generated by liberating a 2.5 KB EcoRI-HindIII fragment from the CMV FoxM1B expression vector. The HindIII site was made blunt by T4 polymerase fill in reaction and then the FoxM1B cDNA fragment
20 was cloned into EcoRI-SmaI sites of the pEGFP-C2 expression plasmid (Clontech). The CMV tetracycline operator (CMV-TO) FoxM1B expression plasmid was generated by excising an EcoRI-BamHI fragment from pEGFP-FoxM1B expression plasmid. The BamHI site was made blunt by a T4 polymerase reaction and then the FoxM1B cDNA

fragment was cloned into EcoRI and EcoRV sites of the pCDNA4-TO expression plasmid (T-Rex system, Invitrogen).

A 6X FoxM1B/FoxA TATA-Luciferase utilized 6 copies of the FoxM1B/FoxA binding site (TTTGTTTGTGTTG; SEQ ID NO: 6) from the cdx-2 promoter region driving
5 expression of the CMV-TATA box luciferase reporter gene as described previously (Rausa *et al.*, 2003, *Mol. Cell. Biol.* 23:437-449; Samadani *et al.*, 1996, *Mol. Cell. Biol.* 16:6273-6284; Ye *et al.*, 1997, *Mol. Cell Biol.* 17:1626-1641).

Example 5

10 **FoxM1B-dependent transcription requires the 596 Cdk phosphorylation site and binding of Cdk1/Cdk2 proteins through the FoxM1B LXLXXL sequence**

Previous transfection studies demonstrated that the FoxM1B transcriptional activation domain was contained within the carboxyl-terminal 365 to 748 amino acid residues (Ye *et. al.*, 1997. *Mol. Cell. Biol.* 17:1626-1641). Searching the FoxM1B C-
15 terminal sequence for Cdk1/2 consensus phosphorylation sites X-pS/T-P-X-R/K revealed three potential Cdk1/2 sites at residues 585, 596 and 657 in the FoxM1B protein (Figure 5A). In order to assess the transcriptional function of these potential FoxM1B Cdk1/2 sites, site-directed mutagenesis was used to alter either Thr or Ser residue to an Ala residue to prevent their Cdk phosphorylation *in vivo*. Transient transfection assays with
20 6X FoxM1B TATA-luciferase reporter and CMV vectors expressing either WT or Cdk1/2 mutant FoxM1B protein revealed that mutation of Cdk1/2 sites at either 585 or 657 resulted in only a marginal decrease (20% to 30%) in FoxM1B transcriptional activity (Figure 5B). In contrast, mutation of the FoxM1B 596 Thr residue (FoxM1B T596A) caused an 80% decrease in transcriptional activity, suggesting that this particular

Cdk1/2 phosphorylation site plays an important role in FoxM1B-dependent transcription (Figure 5B). Moreover, FoxM1B was unable to activate expression of the TATA-luciferase control reporter in cotransfection assays, demonstrating that the multimerized FoxM1B binding sites were required for FoxM1B-dependent transcriptional activation
5 (Figure 5B).

To identify FoxM1B sequences involved in the interaction with Cdk proteins, site-directed mutagenesis was used to convert the Leu 641 residue to an Ala residue thereby disrupting the FoxM1B LXL (639-641) motif shown in Figure 5A, which has been shown to bind to Cdk-Cyclin proteins as efficiently as the Cyclin-binding Cy (RXL)
10 motif (Takeda *et al.*, 2001, *J Biol Chem* 276:1993-1997; Wohlschlegel *et al.*, 2001, *Mol Cell Biol* 21:4868-4874). Transient transfection assays demonstrated that FoxM1B L641A mutant protein displayed an 80% reduction in transcriptional activity (Figure 5B). Furthermore, increasing amounts of the CMV FoxM1B L641A expression vector inhibited transcriptional activity of the WT FoxM1B protein in cotransfection assays,
15 suggesting that the CMV FoxM1B L641A mutant protein functioned as a dominant negative inhibitor. Moreover, both GFP-T7-FoxM1B L641A and GFP-T7-FoxM1B T596A mutant proteins are retained in the nucleus (Fig. 4A-C), indicating that their diminished transcriptional activity was not due to inhibition of nuclear localization.

To determine whether the FoxM1B T596A or FoxM1B L641A mutant proteins
20 exhibited diminished protein association with either the Cdk1 or Cdk2 protein, co-immunoprecipitation (Co-IP) experiments were performed with protein extracts prepared from U2OS cells transfected with either CMV T7-FoxM1B WT or mutant expression constructs (Figure 5C). The transfected U2OS cell extracts were Co-IP with either Cdk1

or Cdk2 antibody and then FoxM1B protein was visualized by Western blot analysis with the T7 epitope Tag monoclonal antibody. These studies demonstrated that CMV T7-FoxM1B L641A mutant protein was unable to interact with either Cdk1 or Cdk2 proteins, whereas the FoxM1B mutant proteins disrupted in each of the Cdk1 phosphorylation sites could efficiently associate with the Cdk proteins (Figure 5C). These results suggested that retention of the second Leu residue within the LXL sequence was essential for interaction between FoxM1B and Cdk proteins, and that FoxM1B binding of either Cdk1 or Cdk2 Cyclin protein complexes was required for its transcriptional activity.

To examine whether the Cdk1-Cyclin B complex phosphorylates the FoxM1B protein, Co-immunoprecipitation (Co-IP) Cdk1 *in vitro* kinase assays were performed with ³²P labeled γ -ATP. Protein extracts prepared from U2OS cells transfected with either CMV GFP-T7-FoxM1B WT or GFP-T7-FoxM1B Cdk mutant expression vectors were co-immunoprecipitated with Cdk-1 antibody and were then used for radioactive Cdk1 *in vitro* kinase assay. The proteins phosphorylated in the Co-IP Cdk1 *in vitro* kinase reaction were resolved on SDS-PAGE and visualized by autoradiography. Consistent with reduced transcriptional activity, the Cdk1 Co-IP kinase assay demonstrated that GFP-T7-FoxM1B T596A mutation exhibited reduced phosphorylation by the Cdk1 protein, whereas Cdk1 phosphorylated the GFP-T7-FoxM1B T585A and GFP-T7-FoxM1B S657A proteins to levels found with the GFP-T7-FoxM1B WT protein (Figure 5D). As expected, the GFP-T7-FoxM1B L641A mutant protein failed to interact efficiently with Cdk1 protein (Figure 5C) and therefore only low levels of FoxM1B L641A mutant protein were available for Cdk1 phosphorylation in the Co-IP Cdk1 kinase assay (Figure 5D).

To examine Cdk phosphorylation *in vivo*, protein extracts were prepared from serum stimulated U2OS cells transfected with either CMV T7-FoxM1B WT, CMV T7-FoxM1B T596A or CMV FoxM1B L641A expression constructs. These protein extracts were IP with the T7 antibody and then Western blot analysis with the MPM2 monoclonal antibody was used to determine Cdk phosphorylation *in vivo*. These results demonstrated that Cdk phosphorylation of T7-FoxM1B WT protein was increased following serum stimulation and that the FoxM1B Thr 596 residue was required for phosphorylation by the Cdk-Cyclin complexes *in vivo* (Figure 5E). Furthermore, *in vivo* Cdk phosphorylation of the T7-FoxM1B L641A mutant protein was significantly reduced (Figure 5E), suggesting that recruitment of the Cdk-Cyclin complex by the FoxM1B LXL sequence was critical for its efficient Cdk phosphorylation *in vivo*.

Example 6

FoxM1B-dependent transcription is stimulated by increased Cdk1 activity and CBP co-activator levels

CMV-FoxM1B and the 6X FoxM1B TATA luciferase constructs were co-transfected with increasing amounts of CMV-DN-Cdk1 or cells were treated with increasing concentration of the pharmacological Cdk1 inhibitor Alsterpaullone (Figure 6A) to demonstrate that Cdk1 activity is necessary for FoxM1B transcriptional activity. Inhibiting Cdk1 activity with either dominant negative (DN) Cdk1 or a pharmacologically active concentration of Alsterpaullone (1 μ M) caused an 80% to 90% reduction in FoxM1B transcriptional activity (Figure 6C). Neither DN-Cdk1 nor Alsterpaullone (1 μ M) altered nuclear localization of transfected CMV GFP-FoxM1B protein (Figure 7A, B and E), suggesting that inhibiting Cdk1 activity alone diminished

FoxM1B-dependent transcription. Furthermore, co-transfection of CMV WT-Myt1 kinase, which negatively regulates Cdk1 activity through phosphorylation, resulted in a 64% reduction in FoxM1B transcriptional activity (Figure 6C). Consistent with these findings, stimulation of Cdk1 activity by co-transfection of either CMV Cdc25B or Cdc25C phosphatases enhanced FoxM1B transcriptional activity by 3.4-fold and 1.7-fold, respectively (Figure 6B and 6D). Furthermore, co-transfection of CMV Cdc25B and CMV CBP together significantly augmented CBP-mediated stimulation of FoxM1B transcriptional activity from 1.4-fold to 6.2-fold increase (Figure 6D). Taken together, these results provided evidence that Cdk1 activity was required to stimulate FoxM1B transcriptional activity.

Example 7

FoxM1B transcriptional activity involves recruitment of CBP through phosphorylation of the FoxM1B 596 Cdk1 site

Co-transfection assays were performed with CMV-CBP or CMV-Adenovirus E1A alone or in combination to determine if FoxM1B transcriptional activity required the CBP co-activator protein. Co-transfection of CMV-CBP stimulated FoxM1B transcriptional activity by 50%, whereas inhibition of CBP function with E1A resulted in a 75% reduction in FoxM1B transcriptional activity (Figure 8A). These studies suggested that recruitment of the p300/CBP family of coactivator proteins was essential for FoxM1B transcriptional activation.

U2OS cells were transiently transfected with CMV-CBP and either CMV GFP-FoxM1B, CMV GFP-FoxM1B comprising an L641A mutation, or CMV GFP-FoxM1B comprising an T596A mutation to determine if the critical FoxM1B 596 Cdk1

phosphorylation site was required for recruitment of CBP. Protein extracts were prepared 48 hours after transfection, and then used for immunoprecipitation with CBP antibody followed by Western blot analysis with GFP monoclonal antibody. These co-IP experiments demonstrated that both WT and FoxM1B L641A mutant proteins could efficiently interacted with the CBP protein (Figure 8B). In contrast, disruption of the FoxM1B Cdk1 phosphorylation site at Thr residue 596 significantly diminished FoxM1B's ability to associate with the CBP protein (Figure 8B). Taken together these results showed that FoxM1B phosphorylation by Cdk1-Cyclin B complex was required for recruitment of the p300/CBP coactivator protein, serving as a mechanism for proliferation-specific stimulation of FoxM1B transcriptional activity.

Example 8

Blocking the Ras-MAPK and PI3K-PDK1 pathways diminished FoxM1B transcriptional activity, but inhibiting Akt did not influence FoxM1B-dependent transcription

The role of the MAPK and PI3K pathways in regulating FoxM1B activity was examined using FoxM1B transcription assays performed in U2OS cells that were either treated with the pharmacological MEK1/2 inhibitor U0126 or PI3K inhibitor Ly294002, or co-transfected with CMV DN-RasN17 expression vector (Figure 9A). These transfection studies demonstrated that inhibition of MEK1/2, PI3K or Ras caused a 70 to 80% reduction in FoxM1B-dependent transcription (Figure 9C), a finding consistent with the important roles of Ras/MAPK and PI3K/PDK1 pathways in Cdk1-Cyclin B activation. In contrast, blocking the Akt pathway with either CMV DN-Akt or the Akt pharmacological kinase inhibitor did not significantly alter FoxM1B transcriptional activity (Figure 9C). Furthermore, combining the MEK1/2 (U0126) and PI3K

(Ly294002) inhibitors resulted in a 90% reduction in FoxM1B-dependent transcription demonstrating the importance of the Ras/MAPK and PI3K/PDK1 pathway in regulating FoxM1B transcriptional activity (Figure 9C). Co-transfection of CMV DN-p90Rsk (Figure 9A) resulted in a 56% reduction in FoxM1B transcriptional activity (Figure 9C), which was similar to the transcriptional reductions found with CMV WT-Myt1 (Figure 6C). Addition of the Ras/MEK1/2 or PI3K/Akt pathway inhibitors did not diminish expression (Figure 9B) or nuclear localization of GFP-FoxM1B protein (Figure 7C, D, G and H), suggesting that these inhibitors caused decreases in FoxM1B transcriptional activity. However, co-transfection of DN-p90Rsk resulted in redistribution of a portion of GFP-FoxM1B fluorescence to the periphery of the nucleus (Figure 7F), suggesting that p90Rsk signaling may influence FoxM1B nuclear localization. Taken together, these studies demonstrated that FoxM1B transcriptional activity required Cdk1-Cyclin B1 activation, which was mediated by growth factor stimulation of the Ras/MAPK and PI3K/PDK1 signaling cascades.

Example 9

Alb-Cre *Foxm1b* ^{-/-} livers fail to develop hepatic adenomas or hepatocellular carcinomas after DEN/PB treatment

A well-established Diethylnitrosamine (DEN)/Phenobarbital (PB) liver tumor induction protocol (see Tamano *et al.*, 1994, *Carcinogenesis* 15:1791-1798; Sargent *et al.*, 1996, *Cancer Res.* 56:2985-91; Kalinina *et al.*, 2003, *Oncogene* 22:6266-6276) was used to determine whether Foxm1b was required for proliferative expansion during mouse liver tumor formation. A single intraperitoneal (IP) injection of the tumor initiator Diethylnitrosamine (DEN) was given at 14 days postnatally to the entire mouse litter

containing both *Foxm1b* fl/fl (control) and Alb-Cre *Foxm1b* -/- (experimental) pups. Two weeks later, the mice were placed on drinking water containing 0.05% of the liver tumor promoter Phenobarbital (PB) for the duration of the liver tumor induction experiment.

5 Eight control *Foxm1b* fl/fl mice and 11 experimental Alb-Cre *Foxm1b* -/- mice were sacrificed at 23 weeks of DEN/PB exposure and seven control *Foxm1b* fl/fl and 13 experimental Alb-Cre *Foxm1b* -/- mice were sacrificed at 33 weeks following DEN/PB treatment (Table 3).

Table 3. Number of tumors per cm² liver tissue after 23 or 33 weeks of DEN/PB treatment

DEN/PB & Sex	<i>Foxm1b</i> fl/fl Mice				Alb-Cre <i>Foxm1b</i> -/- Mice			
	# Mice	² Adenomas	# Mice	Carcinomas	# Mice	Adenomas	# Mice	Carcinomas
23 weeks Male	3	14.2 ± 5.2	3	0.5 ± 1.0	6	0	6	0
33 weeks Male	3	11.2 ± 0.6	3	3.8 ± 0.9	7	0	7	0
23 weeks Female	5	3.5 ± 1.7	5	0	5	0	5	0
33 weeks Female	4	21.0 ± 6.9	4	0	6	0	6	0

10 ¹# Mice: Number of mice (male or female) analyzed for liver tumors after either 23 or 33 weeks of Diethylnitrosamine (DEN)/Phenobarbital (PB) treatment. ²Number of liver tumors per cm² liver tissue ± SD (adenomas or hepatocellular carcinomas greater than 0.1 mm in size) determined from Hematoxylin and Eosin stained liver sections obtained from
15 four different mouse liver lobes.

Livers were harvested from male *Foxm1b* fl/fl and Alb-Cre *Foxm1b* -/- mice after 6 weeks of DEN/PB exposure to provide an early time point during liver tumor promotion. Liver sections were histologically stained with Hematoxylin and Eosin
20 (H&E) and hepatocyte DNA replication was determined by immunofluorescent detection

of BrdU that had been administered in drinking water 4 days before sacrificing the mice following the procedure described in Ledda-Columbano *et al.*, 2002, *Hepatology* 36:1098-1105. After 23 weeks of DEN/PB treatment, H&E stained liver sections from *Foxm1b* fl/fl male mice revealed numerous hepatic adenomas with abundant BrdU labeling (Table 3). Highly proliferative hepatocellular carcinomas (HCC) with abundant BrdU labeling were visible in liver sections from each of the male control *Foxm1b* fl/fl mice following 33 weeks of DEN/PB exposure (Table 3). Furthermore, significant numbers of hyper-proliferative adenomas were found in liver sections from female and male *Foxm1b* fl/fl mice after 33 weeks of DEN/PB treatment (Table 3). No hepatic adenomas or HCC were detected in male or female Alb-Cre *Foxm1b* *-/-* mice at either 23 or 33 weeks following DEN/PB exposure (Table 3). At 6, 23 and 33 weeks following DEN/PB treatment, low levels of BrdU incorporation were found in *Foxm1b* deficient hepatocytes, which was approximately 30% of BrdU labeling levels found in *Foxm1b* fl/fl hepatocytes of non-tumor regions following DEN/PB exposure.

In addition, rabbit polyclonal antibodies specific to α -fetoprotein (AFP) (Dako Corp., Carpinteria, CA) proteins were used for immunohistochemical detection of 5 μ m liver sections using methods described previously (Ye *et al.*, 1997, *Mol Cell Biol* 17:1626-1641; Ye *et al.*, 1999, *Mol. Cell. Biol.* 19:8570-8580; Wang *et al.*, 2002, *J. Biol. Chem.* 277:44310-44316). AFP and BrdU positive immunofluorescent cells were detected in the *Foxm1b* fl/fl HCC liver tumors induced by DEN/PB exposure, which identified proliferating AFP-positive hepatocellular carcinoma cells. Fetal hepatocytes express abundant levels of (AFP), its hepatic expression is extinguished postnatally, but AFP expression is reactivated in HCC (Kunnath and Locker, 1983, *Embo J* 2:317-324;

Chen *et al.*, 1997, *Crit Rev Eukaryot Gene Expr* 7:11-41). Thus, these studies suggested that Foxm1b is required for proliferative expansion during tumor development of hepatic adenomas and HCC.

Together, these experiments demonstrated that male Alb-Cre *Foxm1b* *-/-* mice
5 were resistant to developing HCC in response to 33 weeks of DEN/PB exposure, a treatment sufficient to induce multiple HCC tumors in male *Foxm1b* fl/fl mice (Table 3).

Furthermore, control *Foxm1b* fl/fl and experimental Alb-Cre *Foxm1b* *-/-* mice were treated with DEN/PB for 50 weeks to determine whether *Foxm1b* deficient livers were resistant to a prolonged hepatic tumor induction protocol. After 50 weeks of
10 DEN/PB exposure, all nine female Alb-Cre *Foxm1b* *-/-* mice were devoid of any liver tumors, whereas HCC tumors were found in all four control female livers with one additional control female mouse dying prematurely. Following 50 weeks of DEN/PB exposure, no liver tumors were found in two out of the four male Alb-Cre *Foxm1b* *-/-* mice, while one male mouse exhibited hepatic adenomas and the last male mouse
15 displayed HCC tumors that were negative for Foxm1b protein staining. These studies indicated that following prolonged DEN/PB tumor promotion hepatic tumors were found in a subset of the male Alb-Cre *Foxm1b* *-/-* livers, suggesting that they developed secondary mutations that allowed tumor formation bypassing the block in *Foxm1b* *-/-* hepatocyte proliferation.

20

Example 10

Alb-Cre *Foxm1b* *-/-* male mouse hepatocytes exhibited no elevation in apoptosis and increased hypertrophy in response to DEN/PB treatment

TUNEL staining of liver sections from DEN/PB treated mice was used to determine whether increased apoptosis contributed to the failure of male Alb-Cre *Foxm1b* ^{-/-} mice to develop liver tumors in response to 33 weeks of DEN/PB treatment. The TUNEL assay was performed using the ApoTag Red *in situ* apoptosis detection kit from Intergen (Purchase, NY) according to the manufacturer's recommendations. No difference was found in hepatocyte apoptosis between Alb-Cre *Foxm1b* ^{-/-} and *Foxm1b* fl/fl mice after 6, 23, or 33 weeks of DEN/PB exposure (Figure 10A-C). These results suggested that the absence of liver tumors in *Foxm1b* ^{-/-} mice following DEN/PB exposure was not due to an increase in hepatocyte apoptosis.

Hypertrophy of the Alb-Cre *Foxm1b* ^{-/-} hepatocytes was significantly increased compared to that of control hepatocytes (non-tumor liver regions) at 23 weeks of DEN/PB exposure (Figure 10D-E). A centromere-specific FISH probe purchased from Vysis Inc. (Downers Grove, IL) was used to hybridize paraffin embedded liver sections according to manufacturer's protocol, demonstrating that Alb-Cre *Foxm1b* ^{-/-} hepatocyte nuclei possessed an increase in hybridizing chromosomes compared to control hepatocyte nuclei at 23 weeks of DEN/PB treatment (Figure 10F-G). To quantitate this increase in size, the number of DAPI stained hepatocyte nuclei were counted (per 200X field) in *Foxm1b* fl/fl and Alb-Cre *Foxm1b* ^{-/-} liver sections and the data for each of the time points following DEN/PB exposure was plotted (Figure 10H). The mean number (\pm SD) of DAPI positive hepatocyte nuclei per 1000 cells or 200X field by counting the number of positive hepatocyte nuclei using 5 different 200X liver sections from 3 distinct male mice at the indicated times of DEN/PB exposure or untreated. After 23 or 33 weeks of DEN/PB exposure, half the number of hepatocyte nuclei per 200X field was found in

Foxm1b ^{-/-} livers compared to *Foxm1b* fl/fl control liver (Figure 10H). The data suggested that *Foxm1b* deficient hepatocytes undergo greater hypertrophy and become more polyploid than *Foxm1b* fl/fl control hepatocytes at 23 and 33 weeks of DEN/PB treatment. These results suggested that Alb-Cre *Foxm1b* ^{-/-} hepatocytes exhibited low levels of DNA replication with a significant reduction in mitosis as was previously found in *Foxm1b* deficient hepatocytes during liver regeneration and development (Korver *et al.*, 1998, *Nucleic Acids Res* 25:1715-1719; Wang *et al.*, 2002, *Proc Natl Acad Sci U S A* 99:16881-16886). Moreover, Alb-Cre *Foxm1b* ^{-/-} hepatocytes displayed normal serum levels of albumin, bilirubin and glucose after 33 weeks of DEN/PB exposure indicating that their livers functioned normally.

Example 11

Hepatocyte expression of nuclear Foxm1b protein increases prior to tumor formation and continues during tumor progression

Immunohistochemical staining of liver sections with an antibody specific to Foxm1b protein (Ye *et al.*, 1997, *Mol Cell Biol* 17:1626-1641; Ye *et al.*, 1999, *Mol. Cell. Biol.* 19:8570-8580; Wang *et al.*, 2002, *J. Biol. Chem.* 277:44310-44316) demonstrated that untreated hepatocyte nuclei displayed no significant expression of the Foxm1b protein (Figure 11A-B). Abundant nuclear staining of Foxm1b protein was detected in periportal *Foxm1b* fl/fl hepatocytes as early as 6 weeks of DEN/PB (Figure 11C), yet these hepatocytes failed to exhibit abundant BrdU incorporation levels. High levels of nuclear FoxM1B protein persisted in hyper-proliferative liver adenomas and HCC at 23 weeks and 33 weeks following DEN/PB exposure (Figure 11E and G). As expected, nuclear staining of FoxM1B protein was not found in Alb-Cre *Foxm1b* ^{-/-} hepatocytes at

any of the time points following DEN/PB treatment (Figure 11D, F and H), confirming that the Alb-Cre transgene protein efficiently deleted the *Foxm1b* floxed targeted allele in hepatocytes (Wang *et al.*, 2002, *Proc Natl Acad Sci U S A* 99:16881-16886). These studies demonstrated that hepatocyte nuclear levels of FoxM1B were induced in control
5 hepatocytes prior to tumor formation following DEN/PB treatment and that this nuclear expression persisted in hepatic adenomas and HCC.

Example 12

Alb-Cre *Foxm1b* ^{-/-} livers exhibit normal expression of GST-pi and CAR following DEN/PB treatment

10

Glutathionine-S-transferase placental isoform (GST-pi) is an early marker for “altered enzyme foci” in response to DEN/PB exposure (Hatayama *et al.*, 1993, *Carcinogenesis* 14:537-538). Rabbit polyclonal antibodies specific to GST-pi (Dako Corp., Carpinteria, CA) proteins were used for immunohistochemical detection of 5 μm
15 liver sections using methods described previously (Ye *et al.*, 1997, *Mol Cell Biol* 17:1626-1641; Ye *et al.*, 1999, *Mol. Cell. Biol.* 19:8570-8580; Wang *et al.*, 2002, *J. Biol. Chem.* 277:44310-44316). GST-pi expression was not detected in liver sections of untreated control mice (Figure 12A-B), but both Alb-Cre *Foxm1b* ^{-/-} and *Foxm1b* fl/fl hepatocytes were strongly immunostained for GST-pi after 23 weeks of DEN/PB
20 treatment (Figure 12C-F). Western blot analysis demonstrated that hepatic expression of GST-pi protein was induced as early as 6 weeks following DEN/PB treatment in both Alb-Cre *Foxm1b* ^{-/-} and *Foxm1b* fl/fl livers with continued expression after 23 weeks of DEN/PB exposure (Figure 12G). Phenobarbital (PB) stimulates nuclear translocation of the constitutive androstane receptor (CAR) nuclear receptor (Chawla *et al.*, 2001, *Science*

294:1866-1870). No difference in nuclear staining of the CAR receptor was found between *Foxm1b* fl/fl and Alb-Cre *Foxm1b* ^{-/-} hepatocytes following DEN/PB treatment (Figure 12H-I), indicating that the *Foxm1b* deficient hepatocytes were still responsive to the PB tumor promoter. Taken together, the data suggest that Alb-Cre *Foxm1b* ^{-/-} livers responded normally to DEN/PB tumor induction and expressed the “altered enzyme foci” GST-pi marker, but that they failed to undergo the proliferation required for tumor progression.

Example 13

10 **Persistent nuclear accumulation of the Cdk inhibitor p27^{Kip1} protein and diminished Cdc25B expression in Alb-Cre *Foxm1b* ^{-/-} livers follows DEN/PB exposure**

Liver regeneration studies demonstrated that increased expression of *Foxm1b* protein was associated with reduced hepatocyte nuclear levels of the Cdk inhibitor p27^{Kip1} protein (Wang *et al.*, 2002, *Proc Natl Acad Sci U S A* 99:16881-16886; Wang *et al.*, 2002, *J. Biol. Chem.* 277:44310-44316; Krupczak-Hollis *et al.*, 2003, *Hepatology* 38:1552-1562). Consistent with these findings, persistent nuclear accumulation of hepatocyte p27^{Kip1} protein was found only in Alb-Cre *Foxm1b* ^{-/-} liver sections at 36 hours after partial hepatectomy (PHx; Figure 13A-B). Nuclear expression of p27^{Kip1} protein was examined in mouse liver sections from untreated and DEN/PB treated mice using immunohistochemical staining. Rabbit polyclonal antibodies specific to p27^{Kip1} (Cell Signaling, Beverly, MA) proteins were used for immunohistochemical detection of 5 µm liver sections using methods described previously (Ye *et al.*, 1997, *Mol Cell Biol* 17:1626-1641; Ye *et al.*, 1999, *Mol. Cell. Biol.* 19:8570-8580; Wang *et al.*, 2002, *J. Biol. Chem.* 277:44310-44316). Similar hepatocyte levels of nuclear p27^{Kip1} protein were

found in untreated Alb-Cre *Foxm1b* *-/-* and *Foxm1b* fl/fl mice (Figure 13C-D), a finding consistent with abundant nuclear expression of the Cdk inhibitor p27^{Kip1} protein in quiescent hepatocytes (Kwon *et al.*, 2002, *J Biol Chem* 277:41417-41422). Hepatocyte nuclear staining of p27^{Kip1} protein was significantly diminished in *Foxm1b* fl/fl hepatocytes beginning at 6 weeks and continuing through 33 weeks after DEN/PB treatment (Figure 13E, G, I and M).

Furthermore, nuclear expression of p27^{Kip1} protein was undetectable in hepatic tumor cells at all time points following DEN/PB treatment (Figure 13G and I). In contrast, hepatocyte nuclear staining of p27^{Kip1} protein was sustained in Alb-Cre *Foxm1b* *-/-* mice at 6, 23 and 33 weeks after DEN/PB exposure (Figure 13F, H, J and M). After 50 weeks DEN/PB treatment, nuclear staining of p27^{Kip1} protein was sustained in Female Alb-Cre *Foxm1b* *-/-* mouse hepatocytes (Figure 13K and N) and these livers were resistant to development of adenomas and HCC. In contrast, male Alb-Cre *Foxm1b* *-/-* mouse hepatocytes exhibited nearly undetectable nuclear staining of p27^{Kip1} protein after 50 weeks of DEN/PB exposure (Figure 13L and N) and was associated with 50% of the male Alb-Cre *Foxm1b* *-/-* mice developing liver tumors. These results suggested that an increase in liver tumor incidence in male mice following prolonged response to DEN/PB treatment was associated with loss of hepatocyte nuclear levels of p27^{Kip1} protein.

Diminished hepatocyte DNA replication in regenerating Alb-Cre *Foxm1b* *-/-* livers was associated with increased nuclear levels of the Cdk inhibitor p21^{Cip1} protein (Wang *et al.*, 2002, *Proc Natl Acad Sci U S A* 99:16881-16886). Immunostaining of liver sections demonstrated that nuclear expression of p21^{Cip1} protein in Alb-Cre *Foxm1b* *-/-* and *Foxm1b* fl/fl hepatocytes was similar and restricted to hepatocytes surrounding the

central vein after 6, 23 or 33 weeks of DEN/PB treatment. The similar expression pattern of nuclear p21^{Cip1} protein in hepatocytes of DEN/PB treated mice suggested that elevated p21^{Cip1} protein levels were unlikely to be involved in suppressing tumor formation in Alb-Cre *Foxm1b* ^{-/-} livers.

5 Western blot analysis revealed similar levels of total p27^{Kip1} protein in *Foxm1b* fl/fl and Alb-Cre *Foxm1b* ^{-/-} liver extracts at 6, 23 or 33 weeks following DEN/PB exposure (Figure 14A). These results suggested that *Foxm1b* deficiency resulted in sustained hepatocyte levels of nuclear p27^{Kip1} protein after DEN/PB treatment without changing total expression of the p27^{Kip1} protein.

10 The Western blot was then stripped and probed sequentially with antibodies specific to the Cdk-activating Cdc25B or Cdc25C phosphatases (Santa Cruz Biotech) at a concentration of 1:1000. *Foxm1b* fl/fl control livers exhibited a transient increase in expression of the M-phase promoting Cdc25B phosphatase protein at 6 weeks after DEN/PB exposure, whereas hepatic levels of Cdc25B protein were significantly
15 diminished in Alb-Cre *Foxm1b* ^{-/-} livers (Figure 14A). Similar levels of Cdc25C protein are found in liver extracts from Alb-Cre *Foxm1b* ^{-/-} and *Foxm1b* fl/fl mice after 6 weeks of DEN/PB treatment (Figure 14A). However, diminished hepatic expression of Cdc25B and Cdc25C proteins is observed at either 23 or 33 weeks after DEN/PB exposure (Figure
20 14A). Taken together, the data suggested that decreased proliferation in Alb-Cre *Foxm1b* ^{-/-} hepatocytes was likely due to sustained nuclear levels of Cdk inhibitor p27^{Kip1} protein and diminished expression of the Cdk1-activator Cdc25B.

Example 14

The Cdk inhibitor p27^{Kip1} protein associates with FoxM1B through the Cdk-Cyclin complexes and inhibits its transcriptional activity

FoxM1B transcriptional activity requires an LXL Cdk docking site (639-641) that recruits either the Cdk2-Cyclin E/A (S-phase) or Cdk1-Cyclin B (G2 phase) complexes to the FoxM1B transcriptional activation domain, which is required for efficient phosphorylation of the FoxM1B Cdk 596 site (Major *et al.*, 2004, *Mol. Cell. Biol.* 24:2649-2661). Retention of this Foxm1b Cdk site at Thr 596 residue was found to be essential for transcriptional activity by mediating phosphorylation dependent recruitment of the CREB Binding Protein (CBP) histone acetyltransferase (Major *et al.*, 2004, *Mol. Cell. Biol.* 24:2649-2661).

Protein extracts were prepared from U2OS cells that were transiently transfected with the CMV p27^{Kip1} and CMV expression constructs containing either WT GFP-Foxm1b or the GFP- FoxM1B L641A mutant that failed to interact with the Cdk-Cyclin complexes (Major *et al.*, 2004, *Mol. Cell. Biol.* 24:2649-2661). These U2OS cell transfected lysates were immunoprecipitated (IP) with the p27^{Kip1} antibody (Cell Signaling, Beverly, MA; 1:1000) followed by Western blot analysis with GFP antibody. These Co-IP experiments demonstrated that the p27^{Kip1} protein associated with the WT FoxM1B protein, whereas p27^{Kip1} was unable to bind to the GFP- FoxM1B L641A mutant protein (Figure 14C). These results suggested that the p27^{Kip1} protein associated with the Cdk-Cyclin complexes, which are recruited by the FoxM1B transcriptional activation domain through the LXL Cdk docking motif (Figure 14B).

In addition, U2OS cells were transiently transfected with the 6X FoxM1B - TATA-luciferase reporter plasmid (Rausa *et al.*, 2003, *Mol Cell Biol* 20:8264-8282; Major *et al.*, 2004, *Mol. Cell. Biol.* 24:2649-2661) with the CMV WT FoxM1B and

p27^{Kip1} expression vectors to determine whether the p27^{Kip1} protein could inhibit Foxm1b transcriptional activity. Transfected cells were harvested at 48 hours after transfection and processed for dual luciferase assays to determine FoxM1B transcriptional activity. Cotransfection of p27^{Kip1} expression vector caused a significant reduction in FoxM1B transcriptional activity (Figure 14D). This finding was consistent with the ability of the p27^{Kip1} protein to inhibit kinase activity of the Cdk-Cyclin complexes (Polyak *et al.*, 1994, *Genes Dev* 8:9-22; Zerfass-Thome *et al.*, 1997, *Mol Cell Biol* 17:407-415) required for FoxM1B transcriptional activity through Cdk phosphorylation dependent recruitment of the CBP coactivator protein (Major *et al.*, 2004, *Mol. Cell. Biol.* 24:2649-2661).

Example 15

Endogenous p19^{ARF} tumor suppressor associates with FoxM1B protein in liver extracts prepared from mice following 6 weeks of DEN/PB exposure

Hepatic expression of p19 protein in livers from mice exposed to DEN/PB was examined by Western blot analysis. For Western blotting, 100 µg of total protein extracts prepared from liver following the procedure in Rausa *et al.*, 2000, *Mol Cell Biol* 20:8264-8282) were separated on SDS-PAGE and transferred to PVDF membrane (BioRAD). Rabbit antibodies specific to p19^{ARF} (AB80; GeneTex, San Antonio, TX; 1:750) proteins were used as primary antibody. The primary antibody signals were amplified by HRP-conjugated secondary antibodies (Bio-Rad, Hercules, CA), and detected with Enhanced Chemiluminescence Plus (ECL-plus, Amersham Pharmacia Biotech, Piscataway, NJ).

Western Blot analysis demonstrated that hepatic expression of p19 protein was induced at 6 weeks after DEN/PB exposure, but liver expression of p19 was significantly diminished by 23 weeks following DEN/PB exposure (Figure 15A), a finding consistent

with those obtained with other tumors (Sherr and McCormick, 2002, *Cancer Cell* 2:103-112).

Co-immunoprecipitation (Co-IP) assays were performed with liver protein extracts prepared from *Foxm1b* fl/fl and Alb-Cre *Foxm1b* ^{-/-} mice following either 6 or
5 23 weeks of DEN/PB treatment (Figure 15B) to determine whether the p19 tumor suppressor protein associated with the FoxM1B protein. For Co-IP experiments, 500 µg of protein extract prepared from DEN/PB treated liver were immunoprecipitated with p19^{ARF} antibody (AB80; GeneTex, San Antonio, TX; 2 µg) followed by Western Blot analysis with mouse antibody FoxM1B protein (1:5000). The signals from the primary
10 antibody were amplified by HRP conjugated anti-mouse IgG (Bio-Rad, Hercules, CA), and detected with Enhanced Chemiluminescence Plus (ECL-plus, Amersham Pharmacia Biotech, Piscataway, NJ). As a positive control, Co-IP experiments were performed with protein extracts prepared from mouse embryo fibroblasts (MEFs) that were cultured *in vitro* for 12 passages to induce endogenous protein expression of the p19 tumor
15 suppressor (Kamijo *et al.*, 1997, *Cell* 91:649-659). These Co-IP studies demonstrated efficient association between endogenous FoxM1B and p19 proteins in extracts prepared from either *Foxm1b* fl/fl livers at 6 weeks of DEN/PB exposure or late passage MEFs, but not with liver extracts from Alb-Cre *Foxm1b* ^{-/-} mice (Figure 15B). Negative controls showed that Foxm1b protein failed to Co-IP with p19 in protein extracts
20 prepared from *Foxm1b* fl/fl livers at 23 weeks of DEN/PB treatment, which no longer expressed the p19 protein but continued to express Foxm1b protein (Figure 15B and 11C).

Example 16

FoxM1B and p19 cotransfection assays and synthesis of (D-Arg)₉-p19^{ARF}26-44 peptide

Human osteosarcoma U2OS cells were maintained in DMEM supplemented with
5 10% fetal calf serum, 1X Pen/Strep and 1X L-Glutamine (Gibco). For transient
transfection, U2OS cells were plated in six-well plates and transfected using Fugene 6
reagent (Roche) according to the manufacturer's protocol. Cells were transfected with
500 ng of CMV WT FoxM1B 1-748 alone or with CMV expression vectors containing
either WT T7-p19^{ARF} or N-terminal mutant T7-p19^{ARF} protein (Δ 1-14, Δ 15-25, Δ 26-37, or
10 Δ 26-37 + Δ 1-14) or V5-TAT-p19^{ARF} 26-44 or V5-TAT-p19^{ARF} 26-55 sequences and with
1.5 μ g of a 6X FoxM1B TATA-Luciferase reporter. Ten nanograms of CMV-Renilla
luciferase reporter plasmid were included as an internal control to normalize transfection
efficiency. Cotransfection assays were also performed with 500 ng of CMV FoxM1B 1-
688 and 6X FoxM1B TATA-Luciferase reporter and 10 ng of CMV-Renilla internal
15 control. Twenty-four hours post-transfection, cells were prepared for dual luciferase
assays (Promega). Luciferase activity was determined as percent of wild type FoxM1B
activity following normalization to Renilla activity. Experiments were performed at least
four times in triplicate and mean \pm SD determined.

The Sigma-Genosys company (The Woodlands, TX) synthesized a (D-Arg)₉-
20 p19^{ARF} 26-44 peptide (rrrrrrrrKFVRSRRPRTASCALAFVN; SEQ ID NO: 10)
containing nine D-Arg residues at the N-terminus, which has been demonstrated to
enhance cellular uptake of polypeptides (Wender *et al.*, 2000, *Proc Natl Acad Sci U S A*
97:13003-13008). The (D-Arg)₉-p19^{ARF} 26-44 peptide was tagged with a fluorescent
Lissamine (TRITC) on the N-terminus and acetylated at the C-terminus and was purified

by high-pressure liquid chromatography (Sigma-Genosys). Cotransfection assays were also performed with 500 ng of CMV FoxM1B 1-688, 6X FoxM1B TATA-Luciferase reporter and 10 ng of CMV-Renilla internal control. The transfected U2OS cells were treated with 12 μ M of the p19^{ARF} rrrrrrrrKFVRSRRPRTASCALAFVN (SEQ ID NO: 10) peptide for 24 hours and then harvested for dual luciferase assays (Promega) as described above.

U2OS cells were transiently transfected in 2 well chamber slides (Nunc) with CMV GFP- FoxM1B expression constructs in the presence or absence of either CMV WT T7-p19^{ARF}, CMV HA-p19^{ARF}, or CMV expression constructs containing either N-terminal mutant T7-p19^{ARF} proteins (Δ 1-14, Δ 15-25, or Δ 26-37) or V5-TAT-p19^{ARF} proteins (26-44; SEQ ID NO: 11, or 26-55; SEQ ID NO: 12). U2OS cells were transiently transfected with CMV EGFP expression vector containing the TAT-p19^{ARF} proteins (26-44; SEQ ID NO: 11, or 26-55; SEQ ID NO: 12). Forty-eight hours post transfection, cells were fixed in 4% Para-formaldehyde for 20 minutes at room temperature. GFP fluorescence or immuno-fluorescence with anti-HA antibody following TRITC conjugated secondary antibody was detected using a Zeiss microscope. U2OS cells were treated with 12 μ M of the rrrrrrrrKFVRSRRPRTASCALAFVN (SEQ ID NO: 10) peptide for 24 hours and then analyzed for TRITC fluorescence as described above.

Example 17

Creation of Doxycycline inducible CMV-TETO GFP- FoxM1B U2OS cell line and soft agar assays

The T-RExTM-U2OS cells were purchased from Invitrogen Life Technologies (Catalog No. R712-07). The T-RExTM-U2OS cells express the Tet repressor from pCEP4/*tetR* that was episomally maintained in tissue culture medium containing 10% fetal calf serum and drug selection with 50 µg/ml of Hygromycin B. Tetracycline regulation in the T-REx System was based on the binding of tetracycline to the TET repressor and de-repressing of the CMV-TETO promoter controlling expression of the gene of interest (Yao *et al.*, 1998, *Hum Gene Ther* 9:1939-1950). The pCDNA4-TO GFP- FoxM1B expression plasmid provided in the T-RExTM system was generated as described previously (Major *et al.*, 2004, *Mol. Cell. Biol.* 24:2649-2661) and transfected T-RExTM-U2OS cells with linearized pCDNA4-TO GFP-Foxm1b expression plasmid to select clonal Doxycycline inducible GFP-Foxm1b U2OS cell lines. CMV-TETO GFP-FoxM1B U2OS clones were isolated by selection for three weeks with tissue culture medium containing 50 µg/ml of Hygromycin B and 250 µg/ml of Zeocin. The CMV-TETO GFP-Foxm1b U2OS clone C3 cell line was selected for the soft agar assays because it exhibited intermediate expression of the GFP-Foxm1b fusion protein in response to 1 µg/ml of Doxycycline (Sigma D-9891) as determined by Western blot analysis with GFP monoclonal antibody. Wild type U2OS cells or CMV-TETO GFP-Foxm1b U2OS clone C3 cells were grown in medium with or without 1 µg/ml of Doxycycline for 2 days prior to either adding the (D-Arg)₉-p19^{ARF} 26-44 peptide or left untreated. A concentration of 12 µM of p19^{ARF} peptide (rrrrrrrrKfVRSRRPRTASCALAFVN; SEQ ID NO: 10) was added to the cells for 24 hours prior to splitting the cells for the soft agar assays using procedures described previously (Conzen *et al.* 2000, *Mol Cell Biol* 20:6008-6018). U2OS cells (10⁵) were

plated subconfluently in a 6 well plates in 0.7% agarose on a 1.4% agarose bed in the presence or absence of 12 μ M of the (D-Arg)₉-p19^{ARF} 26-44 peptide and 1 μ g/ml of Doxycycline. Every 4 days the tissue culture medium containing 10% fetal calf serum, 12 μ M of the (D-Arg)₉-p19^{ARF} 26-44 peptide and 1 μ g/ml of Doxycycline was replaced.

5 Controls included growth in medium containing 10% fetal calf serum with or without 1 μ g/ml of Doxycycline. U2OS cell colonies that were larger than 1 mm in size were scored after two weeks of growth on the soft agar.

Example 18

10 **The p19^{ARF} 26 to 44 sequences are sufficient to associate with and inhibit FoxM1B transcriptional activity**

To identify p19^{ARF} protein sequences essential for association with FoxM1B protein, Co-IP assays were performed with protein extracts prepared from transiently transfected U2OS cells, which lack endogenous expression of the p19^{ARF} tumor suppressor protein (Martelli *et al.*, 2001, *Proc Natl Acad Sci U S A* 98:4455-4460).

15 U2OS cells were co-transfected with CMV Green Fluorescent Protein (GFP)- FoxM1B expression vector and CMV expression plasmids containing either WT p19^{ARF} protein or N-terminal deletion mutants of the p19^{ARF} protein (Δ 1-14, Δ 15-25, Δ 26-37, or Δ 26-37 + Δ 1-14) that were fused to the HA epitope tag (Weber *et al.*, 2000, *Mol Cell Biol* 20:2517-

20 2528). Protein extracts were incubated with HA antibody to immunoprecipitate (IP) the HA-p19^{ARF} protein followed by Western blot analysis with a monoclonal antibody specific to GFP protein to detect the GFP- FoxM1B fusion protein. These Co-IP experiments demonstrated that the N-terminal 25 amino acid residues of the p19^{ARF} (p19) protein were dispensable for association with the GFP- FoxM1B protein (Figure 15C-D).

In contrast, the p19 amino acid residues 26 to 37 were essential for association with the GFP-Foxm1b fusion protein (Figure 15C-D). Furthermore, retention of the C-terminal 60 amino acids from the FoxM1B protein (688-748) was required for p19 protein binding (Figure 15C-D).

5 To identify p19 protein sequences that are sufficient for association with FoxM1B protein, Co-IP assays were performed with protein extracts prepared from U2OS cells that were transiently transfected with CMV GFP- FoxM1B expression plasmid and the CMV expression vector containing the V5 epitope tagged p19^{ARF} 26-44 or p19^{ARF} 26-55 sequences. At the amino terminus of either the p19^{ARF} sequences 26 to 44 or 26 to 55,
10 we placed the protein transduction/nuclear localization domain (MGYGRKKRRQRRR; SEQ ID NO: 13) from the HIV-TAT protein (Becker-Hapak *et al.*, 2001, *Methods* 24:247-256). Protein extracts were incubated with the V5 epitope tag antibody to IP the p19 protein followed by Western blot analysis with GFP monoclonal antibody to detect the GFP-FoxM1B fusion protein. These Co-IP experiments demonstrated that p19 amino
15 acid residues 26-44 were sufficient to associate with the FoxM1B protein (Figure 15E).

To determine whether formation of the p19-FoxM1B protein complex could effectively inhibit FoxM1B transcriptional activity, U2OS cells were transiently transfected with the 6X Foxm1b-TATA-luciferase reporter plasmid (Rausa *et al.*, 2003, *Mol. Cell. Biol.* 23:437-449; Major *et al.*, 2004, *Mol. Cell. Biol.* 24:2649-2661) and the
20 CMV WT FoxM1B and p19 expression vectors (Figure 15F). These cotransfection assays demonstrated that both WT p19 and mutant T7-p19^{ARF}Δ1-14, T7-p19^{ARF}Δ15-25, V5-TAT-p19^{ARF} 26-44 and V5-TAT-p19^{ARF} 26-55 proteins that retained their ability to associate with FoxM1B protein (Figure 15D-E) were able to significantly decrease

FoxM1B transcriptional activity (Figure 15F). In contrast, the T7-p19^{ARF}Δ26-37 proteins, which no longer associated with the FoxM1B protein (Figure 15D) were unable to significantly reduce FoxM1B transcriptional activity in these cotransfection assays (Figure 15F). Interestingly, deletion of the FoxM1B C-terminal sequences required for association with p19 protein (Figure 15D; Foxm1b 1-688) was also found to be essential for FoxM1B transcriptional activity (Figure 15F). These studies demonstrated that FoxM1B transcription factor was a novel inhibitory target for the p19^{ARF} tumor suppressor, a finding consistent with the important role of FoxM1B in proliferative expansion during liver tumor progression.

Example 19

The p19^{ARF} tumor suppressor targets FoxM1B protein to the nucleolus

U2OS cell cotransfection studies demonstrated that HA tagged p19 was able to target GFP-FoxM1B fusion protein to the nucleolus (Figure 16A-C). While GFP-FoxM1B 1-748 full-length protein exhibited nuclear staining (Figure 16D), nucleolar targeting of GFP-FoxM1B fusion protein was found in cotransfections with expression vectors containing either WT p19 or mutant p19 proteins that were still able to associate with FoxM1B protein (Figure 16E-F). The GFP-FoxM1B protein was targeted to the nucleolus by expression vectors containing either the V5-TAT-p19^{ARF} 26-44 or V5-TAT-p19^{ARF} 26-55 sequences (Figure 16G-H) and these p19 sequences were also localized to the nucleolus (Figure 16I). In contrast, nuclear fluorescence was found with the GFP-FoxM1B WT protein that was transfected with the CMV p19^{ARF}Δ26-37 mutant that failed to associate with FoxM1B protein (Figure 16J). Likewise, cotransfection assays

with the CMV WT p19 and CMV GFP-FoxM1B 1-688 expression vectors showed nuclear fluorescence of the mutant GFP-Foxm1b 1-688 protein, a finding consistent with this FoxM1B mutant's inability to associate with the p19 protein (Figure 16K and 15B). These studies suggested that association between the p19 tumor suppressor and FoxM1B
5 resulted in targeting FoxM1B to the nucleolus and FoxM1B transcriptional inhibition.

Example 20

(D-Arg)₉ p19^{ARF} 26 to 44 peptide significantly reduces both FoxM1B transcriptional activity and Foxm1b induced cell colony formation on soft agar

10 The p19^{ARF} 26-44 peptide containing nine D-Arg residues at the N-terminus was fluorescently tagged with Lissamine (TRITC) on the N-terminus and acetylated at the C-terminus as described above. Treatment of U2OS cells with 12 μ M of the (D-Arg)₉-p19^{ARF} 26-44 peptide (rrrrrrrrKFVRSRRPRTASCALAFVN; SEQ ID NO: 10) for three days demonstrated that this (D-Arg)₉-p19^{ARF} 26-44 peptide was efficiently transduced
15 into all of the cells and that its fluorescence localized to the nucleolus (Figure 16L). Furthermore, exposure of U2OS cells with 12 μ M of the (D-Arg)₉-p19^{ARF} 26-44 peptide for five days caused neither toxicity nor any increases in apoptosis. Furthermore, treatment of U2OS cells with 12 μ M of the (D-Arg)₉-p19^{ARF} 26-44 peptide that were transfected with CMV- FoxM1B expression vector and the 6X FoxM1B-TATA-
20 luciferase plasmid resulted in significant reduction in FoxM1B transcriptional activity (Figure 17A), suggesting that this p19^{ARF} peptide was an effective inhibitor of FoxM1B transcriptional activity.

In addition, the tetracycline (TET) regulated T-REx™ System described above was used to conditionally express the GFP- FoxM1B protein in U2OS cells to determine

whether conditional overexpression of FoxM1B protein could enhance anchorage-independent growth of U2OS cells. The CMV-TETO GFP- FoxM1B expression plasmid was transfected into T-REx™-U2OS cells (containing TET repressor) and clonal U2OS cell lines were selected that were Doxycycline-inducible for GFP- FoxM1B expression.

5 In response to Doxycycline treatment, the CMV-TETO GFP- FoxM1B U2OS clone C3 cell line displayed inducible intermediate levels of the GFP- FoxM1B fusion protein (Figure 17B). The U2OS clone C3 cell line was selected to examine whether doxycycline induced FoxM1B -GFP expression enhanced anchorage-independent growth as assessed by propagation for two weeks on soft agar (Conzen *et al.*, 2000, *Mol Cell Biol*
10 20:6008-6018). The soft agar experiments demonstrated that induced expression of GFP-FoxM1B protein caused a significant increase in anchorage-independent growth as evidenced by increasing the number and size of U2OS cell colonies on soft agar (Figure 17G and I) compared to uninduced controls (Figure 17F) or the WT U2OS cells (Figure 17C-D).

15 The results suggested that the FoxM1B protein displayed oncogenic properties by stimulating anchorage-independent growth of U2OS cell colonies on soft agar. In order to determine whether the (D-Arg)₉-p19^{ARF} 26-44 peptide inhibited FoxM1B induced colony formation of U2OS cells on soft agar, the Doxycycline induced U2OS clone 3 cells were treated with 12 μM of the (D-Arg)₉-p19^{ARF} 26-44 peptide one day prior to
20 plating and was added at this concentration of (D-Arg)₉-p19^{ARF} 26-44 peptide in the soft agar and growth medium throughout the duration of the experiment as described above. The results of these soft agar studies demonstrated that the (D-Arg)₉-p19^{ARF} 26-44 peptide significantly diminished the ability of induced GFP- FoxM1B to stimulate colony

formation of the U2OS clone C3 cells on soft agar (Figure 17H and I). Furthermore, the (D-Arg)₉-p19^{ARF} 26-44 peptide significantly diminished the ability of the parental U2OS cells to form colonies on soft agar (Figure 17E and I). Taken together these studies suggested that the (D-Arg)₉-p19^{ARF} 26-44 peptide is an effective inhibitor of both
5 FoxM1B mediated transcriptional activation and FoxM1B induced stimulation in anchorage-independent growth that is required for cellular transformation.

It should be understood that the foregoing disclosure emphasizes certain specific embodiments of the invention and that all modifications or alternatives equivalent thereto are within the spirit and scope of the invention as set forth in the appended claims.